

**WATER RECLAMATION SUBSYSTEMS
FOR SPACE STATIONS**

Contract NAS1-2208

by

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ABSTRACT

Three multi-filter subsystems were designed, built, and tested; they were found to give recovered water of the required quality. The dehumidification water subsystem produced potable water from air-conditioning condensate obtained from a space simulator. The washwater subsystem and the fecal water subsystem both produced water suitable for use as wash water.

The actual weights of the multi-filter subsystems for a 1-year mission are:

Dehumidification Water Subsystem	-	9.3 lb
Wash Water Subsystem	-	100.1 lb
Fecal Water Subsystem	-	28.9 lb
Storage racks for spare canisters	-	6.9 lb

These weights are not minimum and could be reduced by further design and development. The frequency of canister replacement, and hence subsystem weights, are highly dependent on the composition of the waste waters. Canister life can best be determined by test operation in a manned space simulator.

Based on the amount of water remaining in the subsystems, the following water recovery efficiencies were calculated:

Dehumidification Water Subsystem	-	99.5%
Wash Water Subsystem	-	99.0%
Fecal Water Subsystem	-	96.0%

TABLE OF CONTENTS

<u>Section</u>	<u>Title</u>	<u>Page</u>
I	INTRODUCTION	1-1
II	DESIGN REQUIREMENTS	2-1
III	WASTE WATER COMPOSITION	3-1
	3.1 General	3-1
	3.2 Dehumidification Water	3-1
	3.3 Wash Water	3-2
	3.4 Fecal Water	3-4
IV	DESIGN STUDY	4-1
	4.1 General	4-1
	4.2 Discussion of Calculations for Wash Water Subsystem	4-3
	4.2.1 Vacuum Distillation with Pyrolysis of Vapor	4-3
	4.2.2 Vapor Compression Distillation	4-4
	4.2.3 Multi-filter System	4-4
	4.2.4 Electrodialysis with Adsorption	4-5
	4.3 Summary of Results for Wash Water Subsystem	4-7
	4.4 Fecal Distillate Subsystem	4-8
	4.4.1 Multi-filter System	4-9
	4.4.2 Distillation-Pyrolysis System	4-9
	4.5 Humidity Recovery Subsystem	4-10
	4.6 Discussion of Multi-filter Subsystems	4-11
V	PRELIMINARY WATER TREATMENT EXPERIMENTS	5-1
	5.1 General	5-1
	5.2 Wash Water Treatment	5-1
	5.3 Fecal Water Treatment	5-2
VI	DISCUSSION OF ACTIVATED CARBON AND ION EXCHANGE RESIN	6-1
	6.1 Theory	6-1
	6.1.1 Activated Carbon	6-1
	6.1.2 Ion Exchange Resin	6-2
	6.2 Carbons and Resins Used in Subsystems	6-4
	6.2.1 Wash Water Subsystem	6-4
	6.2.2 Fecal Water Subsystem	6-4
	6.2.3 Dehumidification Water Subsystem	6-4
	6.3 Loading of Canisters	6-5

TABLE OF CONTENTS (Continued)

<u>Section</u>	<u>Title</u>	<u>Page</u>
VII	CORROSION STUDIES	7-1
	7.1 General	7-1
	7.2 Aluminum in Contact with Waste Waters	7-1
	7.3 Corrosion Tests with Waste Waters, Carbons, and Resins	7-1
	7.4 Corrosion Tests on Coated Aluminum	7-2
VIII	HARDWARE DESCRIPTION	8-1
	8.1 Canisters and Filter Housings	8-1
	8.2 Mounting Supports	8-2
	8.2.1 Alternate Mounting Support Designs	8-2
	8.3 Storage Racks	8-3
	8.4 Notation	8-3
	8.5 System Weight Summary	8-3
IX	TESTING OF SUBSYSTEMS	9-1
	9.1 Wash Water Subsystem	9-1
	9.1.1 Analytical Test Methods	9-2
	9.1.2 Difficulties Encountered	9-2
	9.1.3 Results and Discussion	9-4
	9.1.4 Conclusions and Recommendations	9-6
	9.2 Dehumidification Water Subsystem	9-6
	9.2.1 Analytical Test Methods	9-6
	9.2.2 Difficulties Encountered	9-6
	9.2.3 Results and Discussion	9-7
	9.2.4 Conclusions and Recommendations	9-9
	9.3 Fecal Water Recovery Subsystem	9-9
	9.3.1 Analytical Test Methods	9-10
	9.3.2 Difficulties Encountered	9-10
	9.3.3 Results and Discussion	9-10
	9.3.4 Conclusions and Recommendations	9-11
X	OPERATION OF SUBSYSTEMS	10-1
	10.1 General	10-1
	10.2 Operating Procedure	10-1
XI	CONCLUSIONS	11-1
XII	RECOMMENDATIONS FOR FURTHER STUDY	12-1
BIBLIOGRAPHY		

I

INTRODUCTION

The Langley Research Center is currently engaged in research dealing with life support systems for occupants of space stations. Specialized water reclamation subsystems are required to adequately investigate their use in space cabin simulators. Contract NAS1-2208 encompasses the design study and fabrication of three such subsystems: dehumidification water reclamation, wash water reclamation, and fecal water reclamation. The first subsystem will supply potable water; the other two subsystems will supply wash water.

The first phase of this contract, the design study, was covered in detail in the study report (Steele, et al, 1962). The major objective of the study phase was to select the optimum process for water recovery in each subsystem. A secondary objective was to predict the composition of the waste waters to be reclaimed, since this information is necessary for selecting the optimum recovery process.

The present report summarizes the findings of the design study and covers the second phase of the contract; i.e., the detailed design, fabrication, and testing of the three subsystems.

II

DESIGN REQUIREMENTS

Requirements applicable to all of the subsystems are:

1. Mission time one year.
2. Satisfactory operation under the following environmental conditions:

Total pressure	- 7 to 15 psia
Oxygen partial pressure	- 2.94 psia
Temperature	- 70 to 80°F
Relative humidity	- 40 to 60%
3. Satisfactory operation at any acceleration level from weightless conditions to 1 g.
4. Ability to withstand vibration and acceleration loads imposed during launch of Saturn C-1 or C-5 vehicles.

The specific requirements for each subsystem are:

1. Humidity Reclamation Subsystem - Capacity of 7.5 lb water/day.
To supply potable water from water collected by Government-furnished cabin air dehumidifiers.
2. Wash Water Reclamation Subsystem - Capacity of 12 lb water/day.
To regenerate water used for bathing into re-usable wash water via a batch process.
3. Fecal Water Reclamation Subsystem - Capacity of 1 lb water/day.
To regenerate water obtained from the distillation of feces into re-usable wash water via a batch process.

III

WASTE WATER COMPOSITION

3.1 GENERAL

Prior to undertaking the design calculations, it was necessary to consider the composition of the waste waters to be reclaimed. This information was especially necessary for recovery processes; e.g., adsorption and electrodialysis, the requirements of which, theoretically, vary directly with solute concentration.

3.2 DEHUMIDIFICATION WATER

The water to be treated in this subsystem will be produced by the cabin air dehumidifiers. Broadly speaking, this condensate is expected to be relatively pure water. The exact nature and quantity of contaminants would be very difficult to predict, since they would depend on a number of factors, such as:

1. Type of system used for oxygen supply and CO₂ removal.
2. Auxiliary equipment used for removal of trace contaminants in the cabin atmosphere.
3. Materials of construction used for the condensate coils.
4. Nature of paints, coatings, insulation, etc. used in the cabin and cabin equipment.
5. Nature of lubricants, greases, or other substances used to operate cabin equipment.
6. Degree of contamination of cabin air from other subsystems; e.g., feces collection or storage subsystem.

In spite of the above uncertainties, some useful data is available from current submarine and space cabin simulator systems. This information was summarized by Steele, et al (1962). It was concluded that

the dehumidification water will contain the following maximum impurity levels:

Total solids	- 70 ppm
Total particulate matter	- 25 ppm
Total dissolved solids	- 45 ppm (approx. 1/2 organic and 1/2 inorganic)

This water should be potable except for the possible presence of pathogenic micro-organisms and a slight odor. Actual analysis of a sample of condensate from the Wright-Patterson Air Force Simulator is given in Table 9-2 (first line).

3.3 WASH WATER

In order to select the proper recovery method for wash water, consideration was given to its possible composition and the selection of a suitable body cleansing material. A critical review of existing literature was undertaken with these facts in mind (Steele, et al, 1962).

Used wash water will contain:

1. Four pounds of water per man (neglecting evaporation losses).
2. Additions, such as benzalkonium chloride (BAC), the cleanser of choice (see page 3-3).
3. Secretions of skin; i.e., sweat and sebum.
4. Dirt and skin dust (hair, dead skin, etc.).

The following variables make it difficult to reach definitive conclusions as to the quantitative composition of dirty wash water.

1. Amount of residue on skin would vary depending on temperature, humidity, and amount of dirt in environment.
2. Variations due to activity of subject.
3. Variations due to absorption by clothing.

4. Variations due to intervals between "baths" and method of bathing; e.g., amount of rubbing.
5. Individual variations between subjects.
6. Variations due to diet and amount of water consumed.

It can be assumed, however, that ingredients generally present in sweat will be present in wash water in lesser concentrations.

There are strong presumptive arguments in favor of the use of benzalkonium chloride (BAC) as a cleansing agent for aerospace use.

The advantages of BAC are:

1. It has detergent properties (cationic detergent).
2. Rinsing is not necessary.
3. It has deodorant properties.
4. It is non-irritating.
5. Its germicidal ability will keep various filters, charcoal beds, and ion exchange beds free from odors and microbial action, thereby minimizing cabin contamination and simplifying disposal of these items. It also should be emphasized that part of the wash water will be of fecal origin.

There is ample evidence that BAC can be used without introducing a toxicity hazard. A review of this information was given previously (Steele, et al, 1962).

Based in part on laboratory analyses, the composition of major constituents in typical wash water was estimated to be that summarized in Table 3-1. These values were used for calculating the ion exchange resin and activated carbon requirements for the multi-filter system.

TABLE 3-1

ESTIMATED COMPOSITION OF WASH WATER (MAJOR CONSTITUENTS)

	<u>g/4 lb</u>
Soluble solids (does not include BAC)	1.0
Insoluble solids	1.8
Urea	0.180
Chloride	0.44
BAC	1.82
Lactic acid	0.138
Lipids	0.330

3.4 FECAL WATER

Water for the fecal water reclamation subsystem was to be obtained, originally, from a slurry of water and feces from which the solids were to be removed by a press. Information received from General American Transportation Corporation, the contractor responsible for the fecal water recovery unit, indicates that the water for the fecal water recovery subsystem for the Electric Boat project will be obtained from a distillation unit.

It can be assumed that the odorous, volatile materials and gases present in feces will be carried over into the fecal distillate. These are indole, skatole, hydrogen sulfide, and methylmercaptan (all highly odorous); volatile fatty acids, methane, hydrogen, carbon dioxide, and ammonia with its characteristic odor. It is likewise assumed that fecal distillate also contains volatile organic acids.

The amounts and kinds of volatile constituents in feces will be dependent on the following factors:

1. Variation among individuals (enzymes, age, frequency of defecation).
2. Intestinal flora.
3. Diet consumed.

The results of the work at Electric Boat (Steele, et al, 1962) lead to the conclusion that the fecal distillate to be treated in the fecal water recovery subsystem is a liquid with an extremely unpleasant odor, slight yellow color, and some slight turbidity. Ammonia nitrogen content ranged from 31 to 142 ppm and pH from 2.8 to 4.7. Total solids of a composite sample of fecal distillate was 72 ppm, and ammonia nitrogen was 60 ppm. The distillate contained other volatile ingredients of the original feces samples for which analyses were not performed.

Actual analysis of a sample received from General American Transportation Corporation is given in Table 9-3 (first line). This water had a pH of 9.0, contained 45 ppm total solids, and had a slightly unpleasant odor.

IV

DESIGN STUDY

4.1 GENERAL

This section summarizes the approach and the results of the prior design study (Steele, et al, 1962).

Numerous methods for water reclamation in a space vehicle have been proposed in other studies (Zeff and Bambenek, 1959; Sendroy and Collison, 1959; Wallman and Barnett, 1959; Hawkins, 1958; Okamoto and Konikoff, 1962; Brown, et al, 1963). However, for this study consideration was limited to methods in which the state-of-the-art is in an advanced state of development. The criteria used for selecting these methods were:

1. Reasonably reliable design data should be available.
2. It should be fairly certain that known contaminants in the waste waters would be removed.
3. No extensive development program should be required to demonstrate its feasibility.

Two methods, although considered to meet these criteria, were eliminated from detailed consideration on the basis of prior studies for the reasons stated below.

1. Vacuum (Passive) Distillation - This method requires excessive storage and handling of sponges, and is recommended only for missions of short duration; i.e., a few days (Zeff and Bambenek, 1959).
2. Freeze Drying - This method requires larger heat transfer areas than any of the distillation methods and, therefore, the hardware will weigh more than that necessary for distillation (Zeff and Bambenek, 1959; Wallman and Barnett, 1959).

Based on the above considerations, the design analysis was limited to four methods:

1. Vacuum distillation with pyrolysis of vapor.
2. Vapor compression, with either a) post-treatment of condensate, or b) pyrolysis of vapor.
3. Multi-filtration; i.e., adsorption and ion exchange.
4. Electrodialysis combined with adsorption.

In comparing these four methods, penalties must be assigned for any power that the method uses. This is best done by using a weight penalty factor; i.e., converting the power requirement to an equivalent weight for the power source. Similarly, a penalty factor must be used for any cooling (heat rejection) required. For purposes of this study, the following factors were used:

Power penalty - 300 lb/kw

Heat rejection penalty - 0.01 lb/Btu/hr

The design calculations were made, initially, on the wash water recovery subsystem. This subsystem was selected for the initial study on the basis that its waste water contained the highest concentration of impurities and would, therefore, be the most difficult to purify.

It was assumed that the wash water subsystem would process a 12-lb batch of water in 10 hours. The selection of 10 hours operating time per day was purely arbitrary; however, it was a reasonable compromise between 24 hr/day, which would not allow any time for clean-up, maintenance, or contingencies, and 1 hr/day, which would unnecessarily penalize all systems with respect to size and weight. In any case, the qualitative ratings of the four methods studied should remain the same, as long as the same operating time per day is used for each.

Containers for storing the dirty wash water and treated water were not included in the design comparison. Obviously, these containers are necessary, but since they are common to all four methods, they

will effect each method equally. This means that the "terminals" of each flow sheet will be the points at which the water enters and exits the system.

4.2 DISCUSSION OF CALCULATIONS FOR WASH WATER SUBSYSTEM

The following discussions summarize the design calculations made in the prior design study report (Steele, et al, 1962).

4.2.1 Vacuum Distillation with Pyrolysis of Vapor

This system consists of a vacuum still, a catalytic pyrolysis chamber, a condenser, a feed pump, and two heat economizers. A technical description of this process with regard to such details as catalyst composition and bed temperature was reported by Okamoto and Konikoff (1962).

Electrical energy was assumed as the source of heat for the vacuum distillation system. The power required for this process (assuming negligible heat losses) was found to be quite large (1203 Btu/hr) giving rise to a high power penalty (106 lb).

Attempts to decrease the power-weight penalty by different arrangements of the evaporator, pyrolysis chamber, and heat economizers showed that only a small fraction of the latent heat of vaporization can be recovered as sensible heat for raising the temperature of the feed. The 106 lb taken as the power penalty is the minimum that can be assumed and agrees closely with the 105 lb calculated by scaling down (from 9 to 1.2 lb/hr) a larger vacuum distillation unit operated by Okamoto and Konikoff.

One possible method for eliminating the high power penalty caused by the use of electrical energy in the evaporator is to utilize excess cabin heat (metabolic heat and heat given off by electrical equipment). This could be accomplished by lowering the distillation temperature to about 100°F and using the warm glycol fluid as a heat source before it is sent to the space radiator. Use of this energy is "free" since this

waste heat is rejected to space. Utilization of this waste heat, however, was not allowed for the current design study.

4.2.2 Vapor Compression Distillation

The vapor compression cycle differs from vacuum distillation in that the heat evolved by the (compressed) condensing vapor is utilized to evaporate the feed. In the vacuum distillation cycle all the heat required for vaporization must be supplied from an outside source. Two alternate methods of post-treatment were considered; 1) catalytic pyrolysis of vapor, and 2) filtration of condensate through activated carbon and ion exchange resin.

Equipment necessary for a vapor compression-pyrolysis system consists of a centrifugal evaporator-condenser, a vapor compressor, two pumps, two heat economizers, and a pyrolysis chamber. The same equipment, with the substitution of ion exchange and activated charcoal beds for the pyrolysis chamber and heat economizer make up the vapor compression system with filtration of condensate.

4.2.3 Multi-filter System

Impurities in wash water can be classified into four groups:

1. particulate matter,
2. organic compounds,
3. inorganic compounds, and
4. micro-organisms.

For removal of these impurities, the multi-filter system consists of a filter, an activated carbon bed, and an ion exchange resin bed.

An advantage of the multi-filter system is that it can be operated equally well under normal gravity or weightless conditions. Distillation on the other hand, requires centrifugal force or capillary action for phase separation under weightless conditions.

Activated carbons are generally efficient for adsorption of organic materials. Small organic molecules and dissociated compounds are less

easily adsorbed than are heavy hydrocarbons. Dissociated compounds (usually inorganic) are, on the other hand, removed by ion exchange resins. The phenomenon of ion exchange can be defined briefly as, "the interchange of ions between a solid material and a liquid."

The use of low flow rates (1.2 lb/hr) assumed for the other processes was employed in the multi-filter process. Two major advantages can be obtained by using low flow rates in this process, namely, low pressure drops through the filters and adsorption beds are realized, and close to equilibrium adsorption capacities are attained on granular activated carbon.

Because of the uncertainties with regard to removal of contaminants from a complex mixture, it was decided to calculate the resin and carbon requirements by two methods; 1) from loading factors reported in the literature along with the impurity composition summarized in Section III, and 2) from experimental results with a laboratory multi-filter (Steele, et al, 1962).

4.2.4 Electrodialysis with Adsorption

Electrodialysis is a method for transferring ions from one solution into another solution, using membranes positioned between the two solutions. The solutions and membranes are placed between two electrodes in a d-c circuit. Two types of membranes are used; one has a positive, fixed, ionic charge and will repel cations but will permit passage of anions; the other membrane has a negative fixed charge, repels anions, and allows the passage of cations.

The net result of electrodialysis is similar to that of an ion exchange process. The principal difference between the two processes is the two sources of energy. Electrodialysis requires electrical energy, whereas ion exchange derives its energy from the chemicals used in regeneration. Economically, electrodialysis lends itself to processing more concentrated solutions than ion exchange.

As a unit operation, electrodialysis is well defined and is extensively used on a commercial scale. However, for a complex mixture containing both organic and inorganic contaminants, there are several uncertainties and potential problem areas that can only be resolved by extended test operation. Some of the uncertainties are:

1. Membrane Life

The anion and cation membranes may be chemically attacked under proposed operating conditions. It is also possible that the pores may become plugged or fouled by large-sized ionic or non-ionic particles.

2. Resistance of Membranes

As the membrane surface becomes fouled or plugged, or as ionic concentration at the membrane-solution interface is depleted, the resistance of the stack increases, resulting in an increase in power requirements. For example, Oda, et al (1962) in attempting to remove impurities from sewage, found that detergents of the ABS type caused an appreciable increase in power requirement. The actual resistance of the stack can only be determined by operating data.

3. Precipitation in Sink

The time between changes of the recycling concentrate solution is determined by the solubility of all the salts formed in the sink, which is determined by the contaminants in the wash water.

4. Gassing in Electrode Chambers

Gassing will occur at both electrodes unless steps are taken to prevent it by supplying a special electrode solution. Gassing under zero-gravity conditions would be undesirable.

5. Extent of Removal of Non-ionics

Electrodialysis will remove none of the uncharged particles except those that become absorbed on the membranes or plug the pores of the membranes. Oda, et al reported that large ions, colloidal matter, and uncharged species are not removed appreciably from sewage solutions. Electrodialysis depends, therefore, on a pre-treatment of the wash water to remove non-ionic contaminants and large ions. Brown, et al, 1963, reported that activated carbon pre-treatment, with or without addition of urease, was required for purification of urine by electrodialysis.

The electrodialysis system is comprised of the stack, required replacement stacks, pumps and drives, concentrate tank, and recycle tank. It was assumed that the membranes would have a life of 6 weeks and the stack would be replaced as a unit.

4.3 SUMMARY OF RESULTS FOR WASH WATER SUBSYSTEM

A summary of the estimated weight and reliability ranking for each of the processes investigated (Steele, et al, 1962) is given in Table 4-1. The reliability rankings were qualitatively determined on the basis of probability of breakdown. The factors involved were:

1. The number of rotating machinery components.
2. The number of electrical or electronic parts.
3. The number of components subject to degradation or failure such as the electrodialysis membranes and the high temperature catalyst.

The two processes which are ranked most desirable from the standpoint of weight and reliability are the multi-filter system and the electrodialysis-adsorption system. It is believed that the higher reliability of the multi-filter system overrides the estimated 17 lb weight advantage of the electrodialysis-adsorption system. The latter system requires pumps, electrical controls, and membranes that are subject to failure; there are also some technical uncertainties as pointed out in paragraph 4.2.4. The multi-filter system was therefore recommended for the wash water subsystem.

TABLE 4-1

SUMMARY OF RESULTS FOR WASH WATER SYSTEM
(ONE YEAR MISSION)

Process	Estimated Weight (lb)				Relia- bility Ranking*
	Hardware	Chemicals	Power Plus Cooling Penalties	Total	
Vapor Compression with Pyrolysis	62	--	79	141	III
Vapor Compression with Adsorption	52	7	43	102	II
Vacuum Distillation with Pyrolysis	40	--	117	157	II
Multi-filter	18	68	--	86	I
Electrodialysis with Adsorption	24.5	34.0	10	69	II
*Ranking of I indicates highest relative reliability, III lowest relative reliability.					

4.4 FECAL DISTILLATE SUBSYSTEM

The major impurities in fecal distillate are volatile substances such as ammonia and other odoriferous materials, and constituents which cause color. It is reasonable to assume that since these impurities are found in the distillate from the fecal distillation, they would be carried over in a second distillation. Distillation by itself can therefore be eliminated from further consideration.

It is believed that vapor pyrolysis would be effective in removing odor and color bodies from fecal distillate. For a vapor pyrolysis process, the liquid would have to be vaporized and the resulting system would therefore be identical to the vacuum distillation-pyrolysis or vapor compression-pyrolysis system considered for wash water.

Activated carbon and ion exchange resin were found to be effective in removing both the color and odor from fecal distillate. It was decided, therefore, to briefly compare these two schemes, namely distillation-pyrolysis and the multi-filter, for the fecal water subsystem.

4.4.1 Multi-filter System

A multi-filter system with activated carbon and ion exchange resin was tested with fecal distillate and found satisfactory for 564 ml of effluent (Steele, et al, 1962). Breakthrough was not observed for either odor or color.

The activated carbon and ion exchange requirements for a 1-year mission were calculated by scaling up amounts used in the laboratory system. Using a safety factor of 1.2, the carbon weight comes to 11.7 lb/yr and the resin weight comes to 5.1 lb/yr.

The distillate from an efficient distillation should not contain particulate matter. However, a filter was incorporated in the system in order to remove any solids that might be carried over by entrainment.

The estimated weight of a multi-filter system for fecal distillate is 22.7 lb. This estimated weight, as for the wash water subsystem, is based on periodic replacements of sealed carbon and resin containers.

4.4.2 Distillation-Pyrolysis System

Since the amount of fecal distillate to be purified is only 1 lb/day, an assumption of 10 hours processing time would result in a smaller distillation-pyrolysis system than for the wash water system. There are several reasons why the weight of a distillation-pyrolysis system for the fecal distillate cannot be estimated by making a direct scale-down on the basis of the relative flow rates. These include:

1. Compressor and pump power penalties would not change appreciably since most of the power consumed for these low flow rates is due to frictional losses and the weight:power ratio increases as the power output decreases.

2. The ratio of external surface area:volume increases as the flow rate decreases; therefore, heat losses from the pyrolysis chamber and heat economizer are proportionally higher.
3. The instrumentation weight is the same, regardless of flow rate.
4. Compressor and motor weights would not change appreciably for the small sizes required.

It is felt that even if a weight of 20 lb for a distillation-pyrolysis system for fecal distillate could be achieved, there are several advantages to the use of the multi-filter system for fecal distillate, including:

1. The laboratory multi-filter has been demonstrated to successfully remove the contaminants from fecal distillate.
2. The multi-filter system is much more reliable than either of the distillation-pyrolysis systems because of its lack of moving parts, electrical requirements, and high temperature operation.

4.5 HUMIDITY RECOVERY SUBSYSTEM

It was concluded in Section III of this report that water collected by the air dehumidifiers would be potable, except for the possible presence of pathogenic micro-organisms and a slight odor.

Because of the low impurity level of the air-conditioning condensate, a change of phase treatment is not warranted. Bacteria removal can be effected by membrane filters or by high surface area cartridge filters. Cartridge filters are preferred because of their high capacity and low pressure drop.

Odor and color removal can be accomplished by passing the condensate through a bed of activated carbon. The total weight of the dehumidification system, including filters, carbon, canisters, and mounting was estimated to be 10 lb.

4.6 DISCUSSION OF MULTI-FILTER SUBSYSTEMS

Laboratory tests and design calculations have shown that the adsorption-exchange scheme is preferable to distillation processes for purifying the waste waters considered. These results are contrary to conclusions made by previous investigators who were interested in the purification of urine (Zeff and Bambenek, 1959; Wallman and Barnett, 1959). This difference in findings is obviously due to the fact that the solute concentration in the most contaminated of the three waste waters considered in this report (dirty wash water) is lower than the solute concentration of urine by a factor of 30 (0.16% for wash water compared to 4.8% for urine).

Length of mission is, of course, a significant factor in the choice of process. If a 2-year mission is assumed, the weight of the multi-filter process (without regeneration of carbon or resin) would be almost doubled; the weights of the electrodialysis-adsorption and vapor compression-adsorption systems would be increased somewhat, whereas the weights of the distillation-pyrolysis systems would be virtually unchanged. For a mission shorter than one year, the multi-filter system and other processes employing adsorbents would be lighter and even more desirable.

Larger crew sizes (using more than 12 lb of wash water per day) would tend to decrease the relative weights of the distillation processes in comparison to the adsorption processes. This is due to the fact that the hardware weight and heat losses of a distillation system are proportionally less (per unit of water purified) for higher capacities. Of course, the converse applies for smaller crew sizes.

PRELIMINARY WATER TREATMENT EXPERIMENTS

5.1 GENERAL

Various methods of water reclamation, and design calculations for these methods, have been discussed in the preceding sections. In order to obtain necessary additional design data and to demonstrate the feasibility of the multi-filter concept for wash water and fecal distillate water, a limited experimental program was undertaken (Steele, et al, 1962).

In this program, various constituents of wash water and fecal distillate which could be organoleptically or chemically determined were used as indications of effective treatment with activated carbon and ion exchange resin.

Loading factors were first determined, and an attempt was made to select the most efficient activated carbon and the quantity of carbon and resin required. Laboratory models of the multi-filter were then constructed and tested under continuous flow conditions.

5.2 WASH WATER TREATMENT

Benzalkonium chloride (BAC) and urea were chosen as indicators of activated carbon treatment for wash water. BAC was used because it was added to wash water in amounts of 0.05%. Urea was selected since it is one of the major constituents of perspiration and, therefore, was present in wash water in significant amounts.

The type of ion exchanger was chosen as a result of surveying available commercial resins. Calculations for amount of resin were based on composition of wash water given in Zeff and Bambenek (1959).

Carsten (1952) reported removal of urea from urine using a strongly acid cation exchanger. A few preliminary loading tests indicated promising results and a modest experimental program was undertaken to check adsorption characteristics of selected ion exchangers.

Steele, et al (1962) give details of various loading tests and describe the testing of a laboratory model multi-filter for wash water purification. This laboratory model successfully purified used wash water.

The following ion exchange resins and carbons were also evaluated for urea adsorption:

Ion Exchangers

Duolite C-3 cation exchanger, hydrogen state (Diamond Alkali)

Duolite C-20 polystyrene cation exchanger, sodium state (Diamond Alkali)

Ionac C-111 (Ionac Chemical Co.)

Ionac C-110C (Ionac Chemical Co.)

Ionac C-110N (Ionac Chemical Co.)

Amberlite MB-3 (Rohm and Haas Co.)

Activated Carbons

Permutit Carbo-Dur (The Permutit Co.)

Darco G-60 (Atlas Chemical Industries)

CAL (Pittsburgh Chemical Co.)

PCB (Pittsburgh Chemical Co.)

BPL (Pittsburgh Chemical Co.)

JD-1 (Barneby-Cheney Co.)

JE-1 (Barneby-Cheney Co.)

GI (Barneby-Cheney Co.)

Coconut activated charcoal (Fisher Scientific Co.)

Of the above carbons and exchangers, CAL carbon and C-3 resin showed the most promise in batch loading tests.

BAC was removed efficiently by both carbons and ion exchange resins.

5.3 FECAL WATER TREATMENT

Fecal distillate has a most disagreeable odor and also contains ammonia (and other volatiles). To demonstrate the feasibility of the multi-filter process for conversion into suitable wash water, loading tests

were undertaken with activated carbon and resin using a composite fecal distillate sample. GH-2 carbon and MB-3 resin were found to be the most efficient adsorbers of impurities in fecal water. A laboratory model of a multi-filter system was constructed and tested. This multi-filter system adequately purified fecal distillate and the effluent collected met drinking water standards (Steele, et al, 1962).

VI
DISCUSSION OF ACTIVATED CARBON
AND ION EXCHANGE RESIN

6.1 THEORY

6.1.1 Activated Carbon

Activated carbons are adsorbents made from various raw materials including coal, wood, petroleum coke, shells of nuts, and animal bones. They are used as fine powders and as granular particles (the powders are usually used in batch processes whereas the granular carbons are employed in flow processes). Carbons are usually activated commercially with hot air, high temperature steam, or by heating in furnaces.

A general theoretical treatment of activated carbons is given by Grant (1961).

Adsorption occurs by two mechanisms, both of which operate in activated carbon adsorption. They are:

1. Van der Waal's adsorption, whereby the adsorbents (substances adsorbed) are held by relatively weak forces similar to the physical forces causing the condensation of a vapor.
2. Chemisorption, whereby definite (relatively strong) chemical interaction between the adsorbate molecules and the surface molecules of the adsorbent occur.

Generally, activated carbons are good for adsorbing nonpolar organic substances but are poor adsorbents of inorganic electrolytes.

The property of activated carbon to adsorb relatively large quantities of organic liquids or gases is due to the high surface area of the carbon particles. Most of this surface area is present in the inner structure of the particles available through the network of macroscopic and microscopic pores contained in the particles. The microscopic pores or "micropores" contribute most of the surface area available for adsorption and are largely a product of activation.

The adsorptive capacity of an activated carbon for a particular substance depends on the "pore size distribution" or amount of surface area for pore openings of various diameters. (The diameter of the micropores must be similar in dimension to the diameter of the adsorbent molecules for the carbon to accommodate these molecules.) It is also dependent, to some extent, on the chemical nature of the adsorbent surface. Actual capacities for particular substances are not widely published and must, in most cases, be determined experimentally. In some cases, one type of carbon may be sufficient for removing several impurities from a fluid with a complex of impurities, but in other cases it may be better to use more than one type of carbon for such a task.

Activated carbons are traditionally specified for either liquid or gas phase application. These classifications are based chiefly on past uses of carbons with comparatively large pore sizes for water purification (e.g., most water treatment carbons are used for removing color bodies which are large organic molecules) and carbons with relatively small pore sizes for gas purification. However, the traditional gas purification carbons have been found to be effective in removing odors and other impurities from waste waters.

6.1.2 Ion Exchange Resin

Ion exchange resins are insoluble hydrocarbon polymers to which active acidic or basic groups can be attached. Ion exchange takes place when ions in a liquid solution are interchanged with ions attached to the resin. The process is reversible so the resin can be regenerated.

The chemical nature of ion exchange resins is determined by the nature of the attached ionizable groups. Four major types of ion exchange resin are commercially available; namely, strongly and weakly acidic cation exchangers and strongly and weakly basic anion exchangers. Natural ion exchangers, known as zeolites, are commercially available but are lower in capacity than the synthetic resins.

Ion exchange resins are used for a variety of applications including transformation of ionic constituents, fractionation of ionic substances, concentration of ionic substances, and removal of ionic substances. For separating dissolved salts from solution, cation and anion exchange resins can be used in separate beds in series or in a mixed bed. If the interchangeable ions on the cation and anion exchangers are H^+ and OH^- respectively, the overall result of removing a salt from solution is interchanging H^+ ions for the cation of the salt and OH^- ions for the anions of the salt, resulting in the production of water. This is, of course, a desirable result when purifying waste waters for re-use.

It is possible, in some cases, to increase the capacity of ion exchange resins (on a volume or weight basis) by pretreatment. For example, in the case when it is desired to remove NaCl (this is the case for purification of dirty wash water) or other soluble chlorides from solution, a strong cation exchange resin pretreated with a solution of $AgNO_3$ is believed to be efficient in removing the salts (Kunin, 1962). The active ion on the cation exchange resin, in this case, is the silver ion which combines with the chlorine of the dissolved chloride to give silver chloride which precipitates. The cation of the dissolved salt (e.g., Na^+) takes the place of the silver ion on the resin. Even though this technique seems very desirable at first consideration (since no anion exchange resin is required), there are problems that must be solved before use of the "silver salt" cation exchange resin can be made. These are:

1. The precipitated silver chloride can appear in the effluent from a column with this resin (Kunin, 1962).
2. Additional resin beds must be used for separating out other inorganic impurities not forming insoluble silver salts.
3. It is possible that the precipitated silver salt would block some of the pores of the resin making it impossible to approach theoretical capacity.

An experimental program aimed at solving these problems would be useful in determining the practicability of the use of the "silver salt" technique.

6.2 CARBONS AND RESINS USED IN SUBSYSTEMS

6.2.1 Wash Water Subsystem

Pittsburgh type CAL activated carbon was chosen for the wash water subsystem on the basis of its comparatively high capacity for benzalkonium chloride and urea. The ion exchange resins chosen for the wash water system were Rohm and Haas IR-120 strongly acidic cation exchange resin followed by Rohm and Haas XE-168 weakly basic anion exchange resin. This combination was recommended by Rohm and Haas to give a higher capacity on a weight basis than a single mixed bed or strongly acidic cation and strongly basic anion exchange resins in series. In addition to the Rohm and Haas IR-120 and XE-168, a bed of Duolite C-3 cation exchange resin was included for removal of urea not adsorbed by the activated carbon. The Duolite C-3 is followed by a bed of Rohm and Haas XE-168 in order to adjust the pH of the final effluent (see Section IX). The quantities of cation and anion exchange resins used were determined by the operating capacities for these resins.

6.2.2 Fecal Water Subsystem

The activated carbon initially selected on the basis of laboratory tests for use in the fecal water subsystem (Barnebey-Cheney GH-2) was available for purchase on a 60-90 day delivery only and consequently could not be used. Barnebey-Cheney Type KE-1 was chosen as an alternative on the basis of batch loading tests with type JE-1. (Types KE-1 and JE-1 are the same carbons except for mesh size.) The ion exchange resin selected for the fecal water subsystem was Rohm and Haas MB-1 monobed.

6.2.3 Dehumidification Water Subsystem

Barnebey-Cheney Type KE-1 (the same carbon as that used in the fecal water subsystem) was chosen for the dehumidification water subsystem.

A summary of the activated carbons, ion exchange resins, and filter elements used for the three subsystems is shown in Table 6-1.

6.3 LOADING OF CANISTERS

Before loading canisters with activated carbons, the carbon was blown free of dust particles with air. The carbon was loaded into the canisters in the dry state, the canister being tapped often to fill any voids. Because of the presence of appreciable amounts of soluble salts in the Barnebey-Cheney KE-1 (see Section IX, paragraph 9.2), canisters loaded with this carbon had to be washed free of salts with de-ionized water and then dried. Dacron felt pads were placed at the ends of the carbon and resin canisters as liquid distributors and also to keep carbon and resin particles from passing into the effluent stream.

Ion exchange resins were loaded into the canisters in the wetted state. Each bed was packed tightly with a wooden plunger before the following bed was loaded.

TABLE 6-1
CARBONS, RESINS, AND FILTER ELEMENTS FOR THREE SUBSYSTEMS

Activated Carbon (Note 1)	No. Canisters (Total/Stored)	WASH WATER SUBSYSTEM	FECAL WATER SUBSYSTEM	DEHUMIDIFICATION WATER SUBSYSTEM
Ion Exchange Resin (Note 1)	Contents (Each Canister)	2.19 lb Pittsburgh Type CAL	2.80 lb Barnebey- Cheney KE-1	2.80 lb Barnebey-Cheney KE-1
	Total Wt. (1-yr Mission)	28.5 lb	14.0 lb	5.6 lb
	No. Canisters (Total/Stored)	12/11	2/1	0/0
	Contents (Each Canister)	1.34 lb Rohm and Haas IR-120 1.48 lb Rohm and Haas XE-168 0.63 lb Duolite C-3 0.49 lb Rohm and Haas XE-168	3.55 lb Rohm and Haas MB-1	
Filter Element (Note 2)	Total Wt. (1-yr Mission)	47.3 lb	7.10 lb	--
	No. Filters (Total/Stored)	12/11	2/1	4/3
	Type Filter Elements	Pall ACF 4463 EL 3 Micron Rating	Pall ACF 4463 EL 3 Micron Rating	Pall ACF 4463 UWA 0.45 μ Bacteria Filter
	Total Wt. Elements (1-yr Mission)	2.45 lb	0.41 lb	0.82 lb

1. All carbon and resin canisters are the same in dimensions, namely 4.0" outer diameter X 12 9/16" long.
2. All particulate and bacteria filters are the same dimensions, namely 2.5" outer diameter X 6 3/32" long.

VII

CORROSION STUDIES

7.1 GENERAL

Aluminum alloy (type 6061) was used as the basic construction material for the canisters and filters (see Section VIII). This material was selected to minimize the weight of the subsystem. Various preliminary corrosion tests were run to confirm the suitability of this material.

7.2 ALUMINUM IN CONTACT WITH WASTE WATERS

Test strips of 6061 aluminum alloy were partially immersed in untreated fecal distillate and dirty wash water to determine whether or not the metal would corrode when in continuous contact with these waste waters. After one month's time, no corrosion or pitting was visible on either sample and no weight loss occurred. Surface discoloration did appear on the sample immersed in fecal distillate, but it was not indicative of any unusual corrosion.

7.3 CORROSION TESTS WITH WASTE WATERS, CARBONS, AND RESINS

Even though the samples of aluminum immersed in waste waters showed no signs of corrosion, a prototype carbon canister rinsed out with water, drained, ground open, and left open for a few weeks did show some slight localized pitting. It was decided, therefore, to conduct corrosion tests on aluminum samples immersed in carbons, resins, and waste water to duplicate operating conditions. The results of these tests are shown in Table 7-1.

Aluminum strips approximately 1" x 2" x 0.025" were first polished with 400 and 600 grain emery to remove any films or oil which may have coated the aluminum. All samples were tested for two periods of at least 48 hours. Corrosion rates were calculated and found to be moderately low (from 1 to approximately 10 mils penetration/yr). Metals with corrosion rates of 2-20 mils/yr are normally rated "good." For the 1 to 6-month service anticipated for the carbon and resin canisters, the calculated rates of corrosion can be considered acceptable.

Some slight pitting was observed along the interface of samples 4, 6, and 9 and slight pitting occurred on the top half of sample 9. Corrosive coatings were removed by either rubbing off or by using 400 grain emery. It can be concluded from these tests that limited corrosion occurs on 6061 aluminum alloy immersed completely in waste waters with carbons or resins, and slight pitting can occur on aluminum in the presence of damp carbon.

7.4 CORROSION TESTS ON COATED ALUMINUM

A set of accelerated tests was made to determine the effectiveness of various coatings in protecting aluminum. The tests were made with anodized samples and vinyl and epoxy coated samples, the latter two pre-treated as shown below:

Vinyl Coating

1. Cleaned with isopropanol; deoxidine and alodine preparation.
2. Navy formula 117 and 120 vinyl coatings.

Epoxy Coating

1. Cleaned with isopropanol; deoxidine and alodine preparation.
2. Devran 204 (Devroe and Reynolds) epoxy coating.

Each type of sample was immersed in the following ion exchange resins: Rohm and Hass IR-120, XE-168, MB-3, and Duolite C-3.

The samples were examined after 65 hours of contact. The anodized samples showed no significant improvement as compared with uncoated aluminum. The vinyl coated samples with deoxidine and alodine surface preparation gave the highest overall resistance to attack. Five of the resin canisters were thus vinyl coated. The coated canisters and the canisters left uncoated can be observed at a later date to determine whether or not any serious corrosion occurs in actual use.

TABLE 7-1
CORROSION TEST ON ALUMINUM ALLOY¹

Sample No.	Water-Adsorbent Test Medium	Test Period	Time (hr)	Wt. Loss (g)	Corrosion Rate (mil/yr)
1	Pittsburgh CAL in wash water	First Second	90.3 73.5	0.0068 0.0071	6.7 8.6
2	Barnebey-Cheney GH-2 in fecal water	First Second	93.8 55	0.0010 0.0014	0.84 2.0
3	Rohm and Haas IR-120 in wash water	First Second	112.5 53.8	0.0087 0.0032	6.3 4.9
4	Barnebey-Cheney KE-1 in fecal water	First Second	117.7 49.6	0.0056 0.0012	3.5 1.8
5	Rohm and Haas IR-120 in fecal water	First Second	118 49.3	0.0067 0.0026	4.5 4.2
6	Rohm and Haas MB-1 in fecal water	First Second	118.3 48.3	0.0181 0.0097	13.7 ² 17.9
7	Rohm and Haas XE-168 in wash water	First Second	119 48.2	0.0013 0.0005	0.98 0.8
8	Duolite C-3 in wash water	First Second	119 48.1	0.0120 0.0045	9.83 9.1
9	Pittsburgh CAL in tap water	First Second	119.5 48	0.0146 0.0064	5.98 6.5

¹Test Conditions were as follows:

Sample size - 2" x 1" x 0.025"
Sample wt. - ~ 2.1 g; temp. - 26 - 29°C; samples 1-8 were approximately half immersed in adsorbent and waste water. Sample 9 was immersed completely in carbon, the top half of the carbon damp, the bottom half completely wet.

²The tough coating formed on sample 6 was removed with 400 grain emery. Appreciable amounts of aluminum were removed with the emery so that the actual corrosion rate is lower than that calculated (probably 1/2 or less).

VIII

HARDWARE DESCRIPTION

8.1 CANISTERS AND FILTER HOUSINGS

Aluminum and transparent plastic were considered as possible materials of construction for the ion exchange resin canisters and for the filter housings. Transparent housings would allow use of a color-indicating ion exchange resin and would allow visible inspection of the filter element, to determine the point of exhaustion. Calculations showed that the use of plastic for these canisters and filter housings would increase the total weight of the three subsystems by about 7 lb over that of aluminum. It was therefore decided to use aluminum for construction of these containers as well as for fabricating the carbon canisters. The thickness of the carbon and resin containers (0.025") is sufficient for them to withstand a pressure differential (internal or external) of 15 psig.

Welding, dip brazing, and the use of an epoxy-aluminum adhesive (80% aluminum and 20% epoxy) were three canister fabrication techniques considered. The epoxy-aluminum mixture was eliminated from further consideration since it is not considered to be as reliable as welding (the strength of the bond is markedly dependent on proper etching of the aluminum and on proper application of the adhesive). Dip brazing, although felt to be an effective method for bonding aluminum, was not used since it involves relatively high temperatures and this process could not be used in the final seal joint enclosing ion exchange resin or a pleated cartridge filter. Therefore, heliarc welding was used. In order to protect the resins and filter cartridges from excessive heat, an extended joint design was used and all containers were immersed in water approximately 1/2" from the top brim when making the final seal weld. Inspection following sectioning of a prototype resin canister and filter sealed in this manner showed that no damage occurred.

Details of the carbon (and resin) canister are shown in Figures 8-1, 8-2, and 8-3. Details of the filter are shown in Figures 8-4 and 8-5.

8.2 MOUNTING SUPPORTS

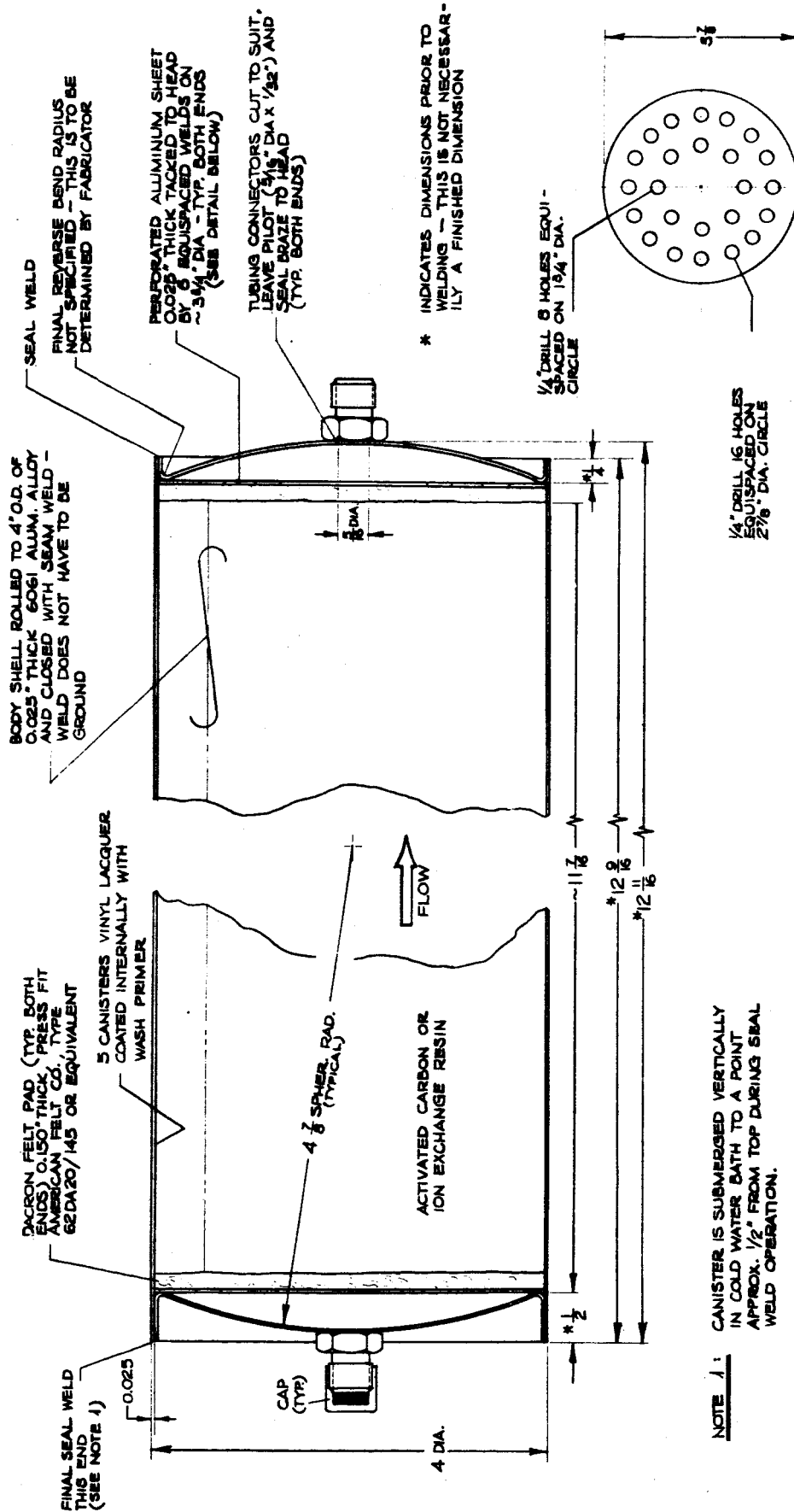
Three alternate designs considered for mounting supports for the canisters are shown below. Comments indicating the reason for selection or rejection of design are included.

8.2.1 Alternate Mounting Support Designs

<u>Design</u>	<u>Comments</u>
1. Spring clamps	1. Springs strong enough to support the canisters would be very stiff and make "zero g" mounting difficult.
2. Use of metal straps	2. Supports in addition to straps needed. Manual mounting difficulties anticipated.
3. Beveled canister retainers mounted on aluminum channel frame.	3. Believed to be the most reliable and lightest support.

The beveled canister retainers mounted on an aluminum channel frame were adopted for mounting of the three subsystems. Figures 8-6, 8-7, and 8-8 show the three mountings with canisters. Sealed connections between canisters were made with 1/4-inch, translucent polypropylene tubing using aluminum connectors incorporating a round knurled nut and aluminum insert (see Figures 8-2 and 8-3).

Polypropylene tubing was chosen because of its excellent physical and chemical properties including light weight, abrasion and corrosion resistance, lack of odor and taste, plus the fact it is easily worked. Tubing connectors were used rather than quick-disconnect fittings since the latter spill small quantities of liquid when disconnected and they



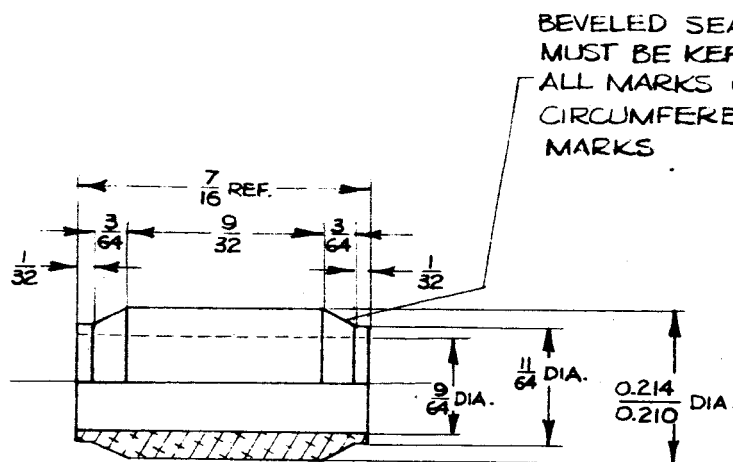
NOTE 1: CANISTER IS SUBMERGED VERTICALLY IN COLD WATER BATH TO A POINT APPROX. 1/2" FROM TOP DURING SEAL WELD OPERATION.

DETAIL - PERFORATED SHEET
 SCALE: HALF SIZE

figure 8-1
 CARBON & RESIN CANISTER DETAIL
 MAT'L: 6061 ALUMINUM
 (TEMPERED TO T4 AFTER FABRICATION)



FIGURE 8-2 COMPONENTS OF CARBON (AND RESIN) CANISTERS

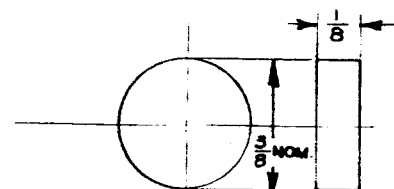


EXPANDER INSERT

SCALE: 4" = 1"

NO. REQ'D: 35

MAT'L: 6061-T6 ALUM.

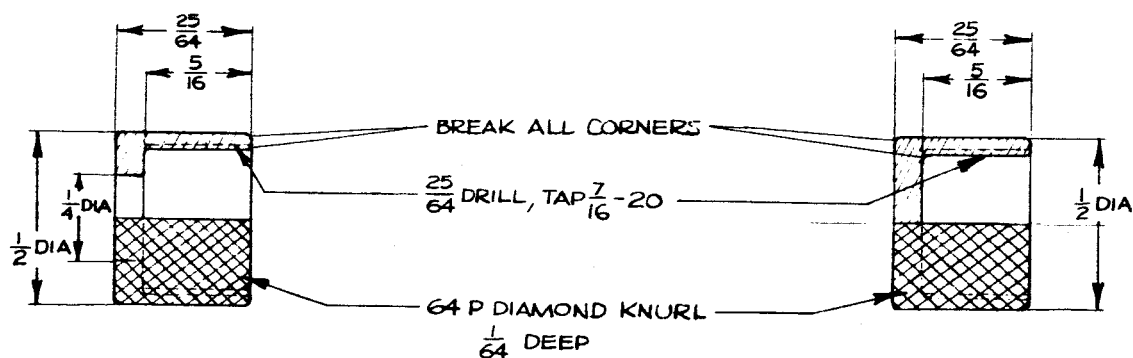


GASKET (FOR PRESS FIT IN CAP)

SCALE: DOUBLE SIZE

NO. REQ'D: 84

MAT'L: NEOPRENE,
(40-50 DUROMETER)



NUT

SCALE: DOUBLE SIZE

NO. REQ'D: 35

MAT'L: 6061-T6 ALUM.

CAP

SCALE: DOUBLE SIZE

NO. REQ'D: 84

MAT'L: 6061-T6 ALUM.

figure 8-3

SPECIAL TUBE FITTINGS (DETAILS)



FILTER CANISTER DETAIL

MAT'L: 6061 ALUM.
(TEMPERED TO T4 AFTER FABRICATION)

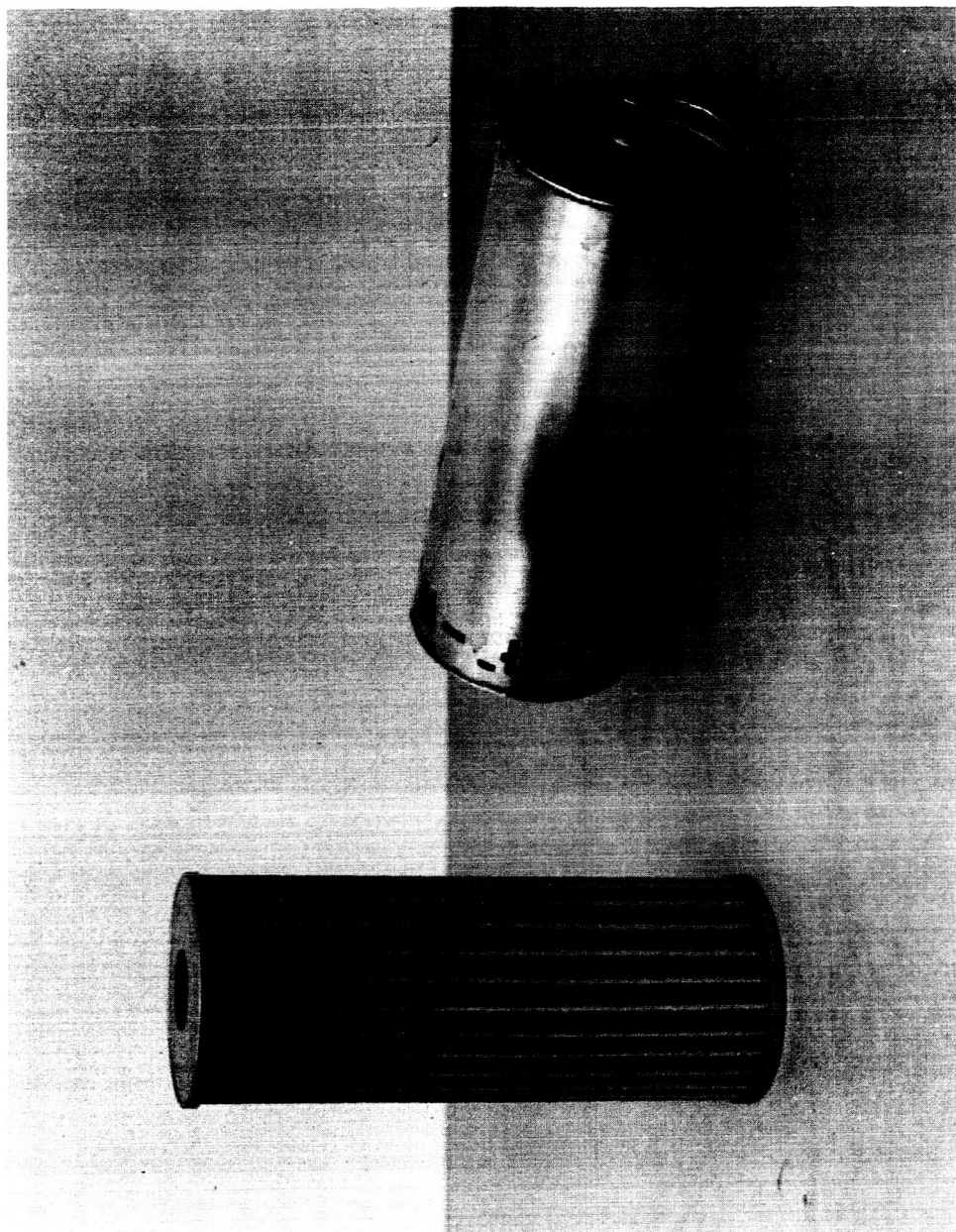


FIGURE 8-5 FILTER AND CANISTER

- (1) To reclaimed water tank
- (2) Sample line
- (3) Compressed air supply
- (4) From waste water storage tank
- (5) Carbon canister
- (6) Bacterial filter
- (7) Two way valves

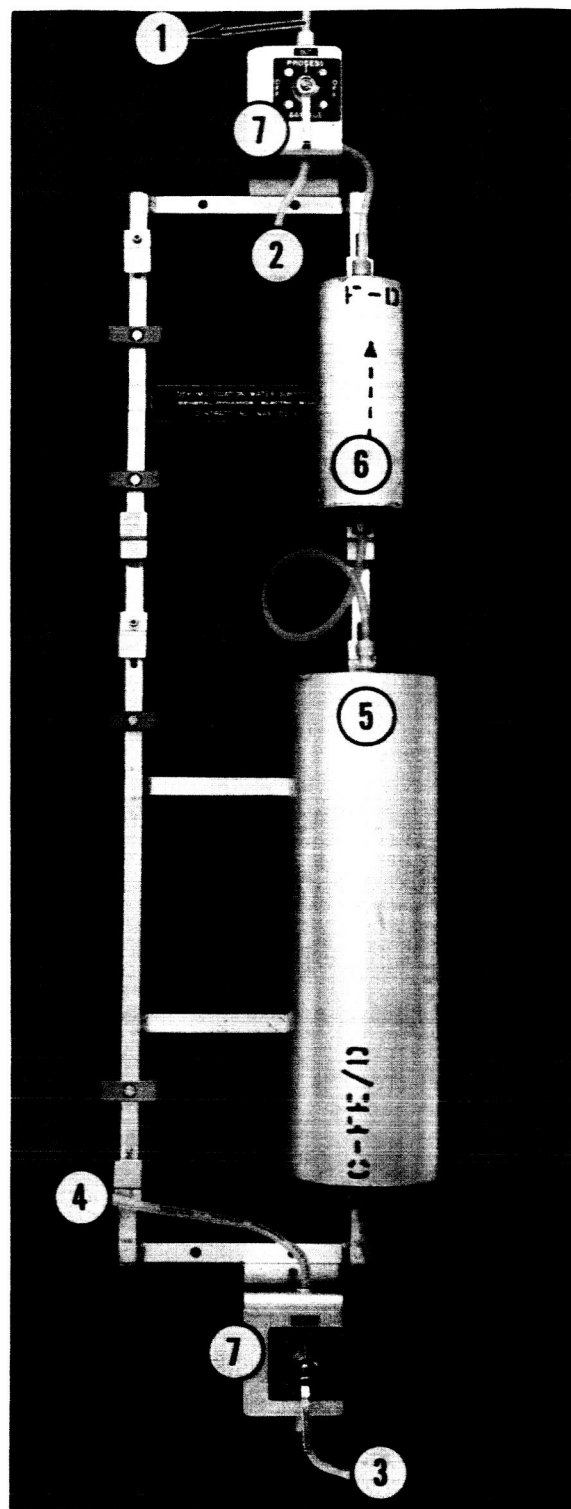


FIGURE 8-6 DEHUMIDIFICATION WATER SUBSYSTEM

- (1) To reclaimed water storage tank
- (2) Sample line
- (3) Compressed air supply
- (4) From waste water storage tank
- (5) Carbon canisters
- (6) Resin canister
- (7) Particulate filter
- (8) Beveled canister retainer
- (9) Phenolic plastic canister saddle
- (10) Aluminum channel frame
- (11) Two-way valves
- (12) Replacement support position

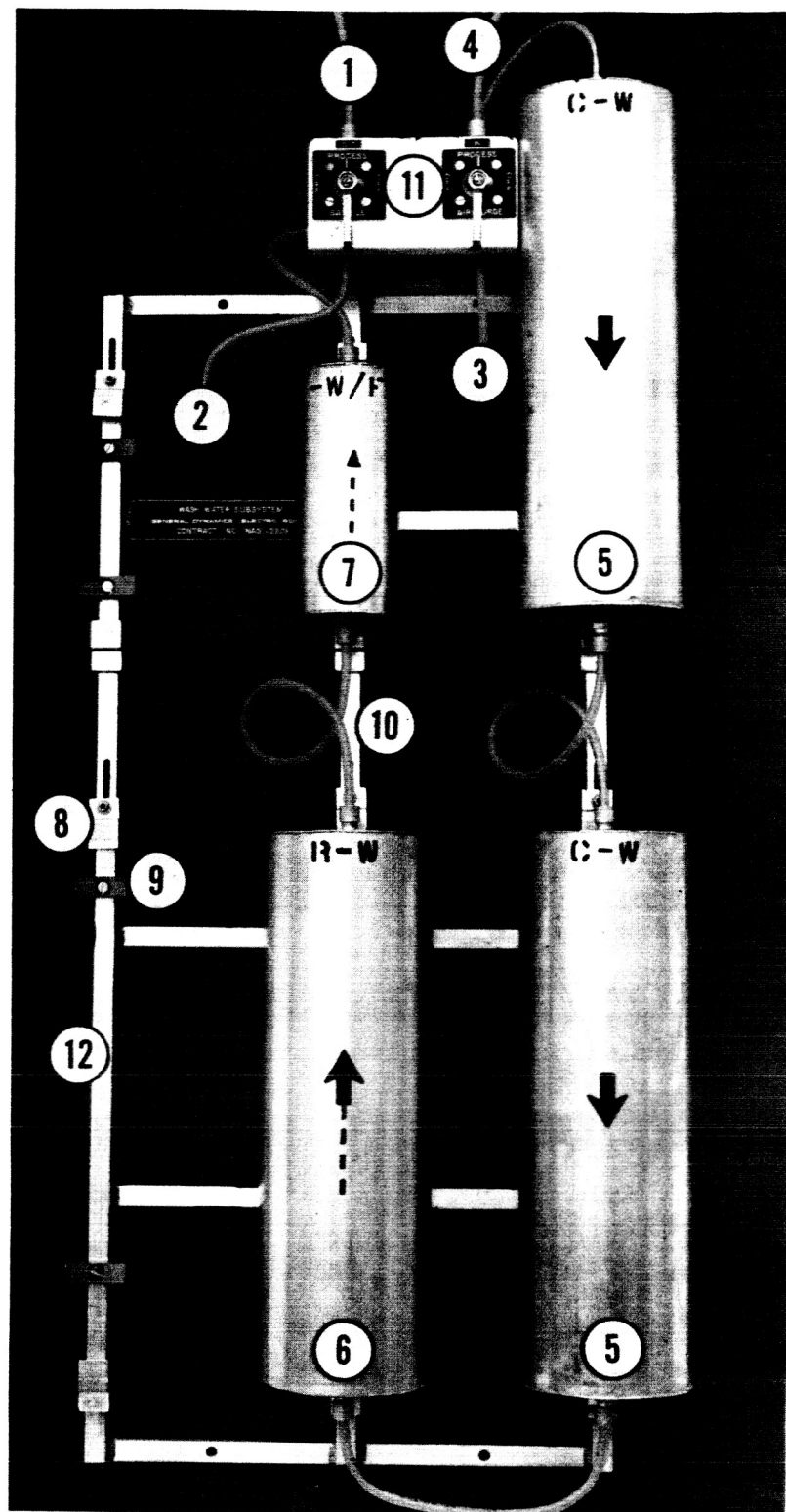


FIGURE 8-7 WASH WATER SUBSYSTEM

- (1) To reclaimed water storage tank
- (2) Sample line
- (3) Compressed air supply
- (4) From waste water storage tank
- (5) Carbon canisters
- (6) Resin canister
- (7) Particulate filter
- (8) Beveled canister retainer
- (9) Phenolic plastic canister saddle
- (10) Aluminum channel frame
- (11) Two way valves
- (12) Replacement support position

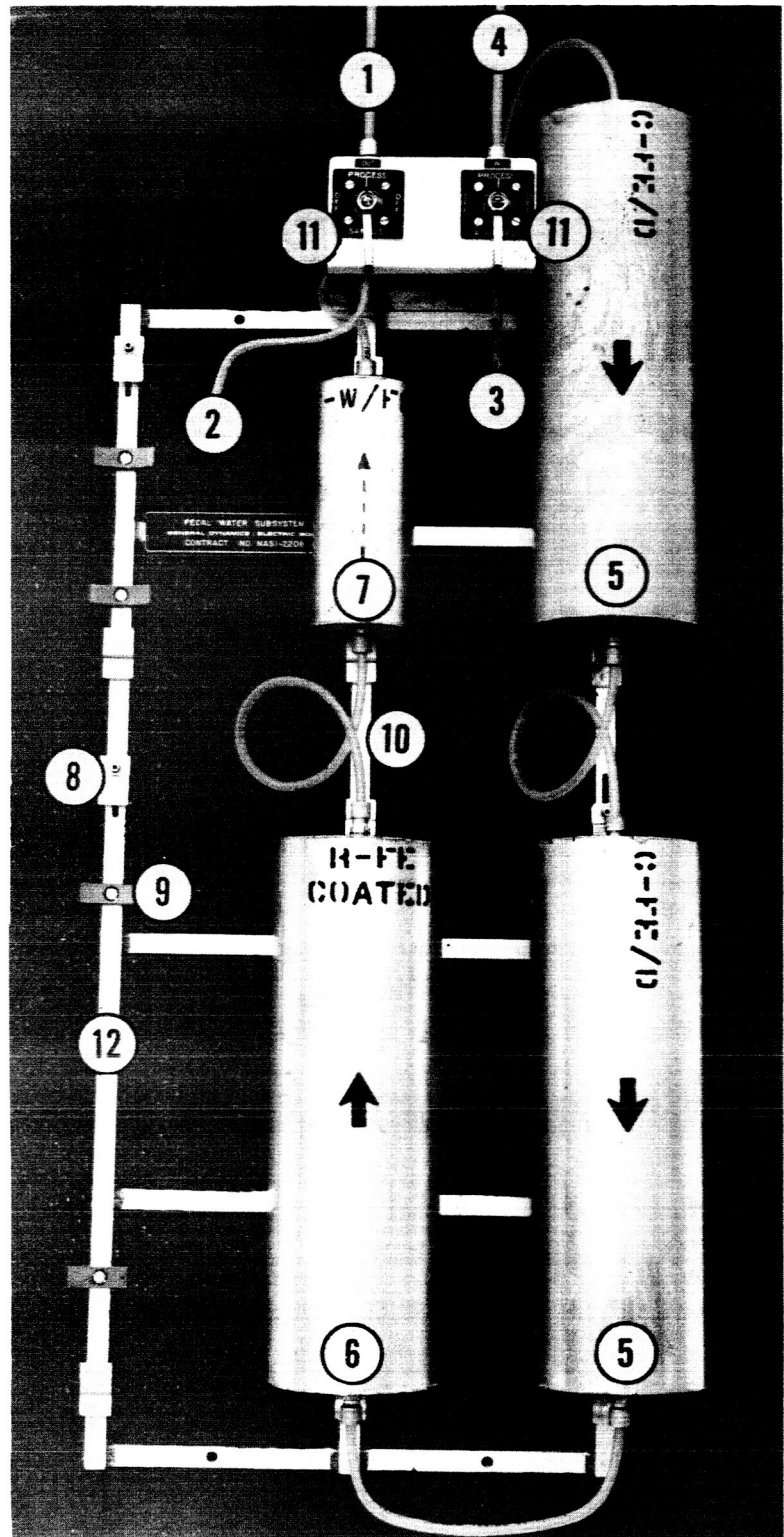


FIGURE 8-8 FECAL WATER SUBSYSTEM

are relatively heavy. Each mounting has a spare position with supports to be used when changing canisters and/or filters.

8.3 STORAGE RACKS

Storage of spare canisters and filters for the 1-year mission is provided for in racks made of thin-wall aluminum tubing (1/4" O.D. x 0.48" wall and 1/2" O.D. x 0.49" wall) welded together. Nylon straps with brass grommets and snaps hold the canisters in place. (A weight savings could be realized with aluminum grommets and snaps instead of brass, but these were not available at time of fabrication.) Figure 8-9 shows the finished storage containers with spare canisters and filters.

8.4 NOTATION

All canisters and filters were stenciled with black ink to identify the contents. The first letter indicates whether the container holds activated carbon (C), ion exchange resin (R), or a filter cartridge (F). The remaining letters denote what system or systems the canister or filter should be used in. (In emergencies the different canisters and filters may be interchanged, see Section X.) Arrows specify the direction of flow where necessary. Table 8-1 is a list of the notations used.

TABLE 8-1
NOTATION ON CANISTERS AND FILTERS

Notation	Definition
C-W	Activated carbon for wash water subsystem.
C-FE/D	Activated carbon for fecal water or dehumidification water subsystem.
R-W	Ion exchange resin for wash water subsystem.
R-FE	Ion exchange resin for fecal water subsystem.
F-D	Filter (bacterial) for dehumidification water subsystem.
F-W/FE	Filter for wash water or fecal water subsystem.

8.5 SYSTEM WEIGHT SUMMARY

Design of the water reclamation hardware was made with minimizing weight as a primary objective. A summary of the measured weights is given in

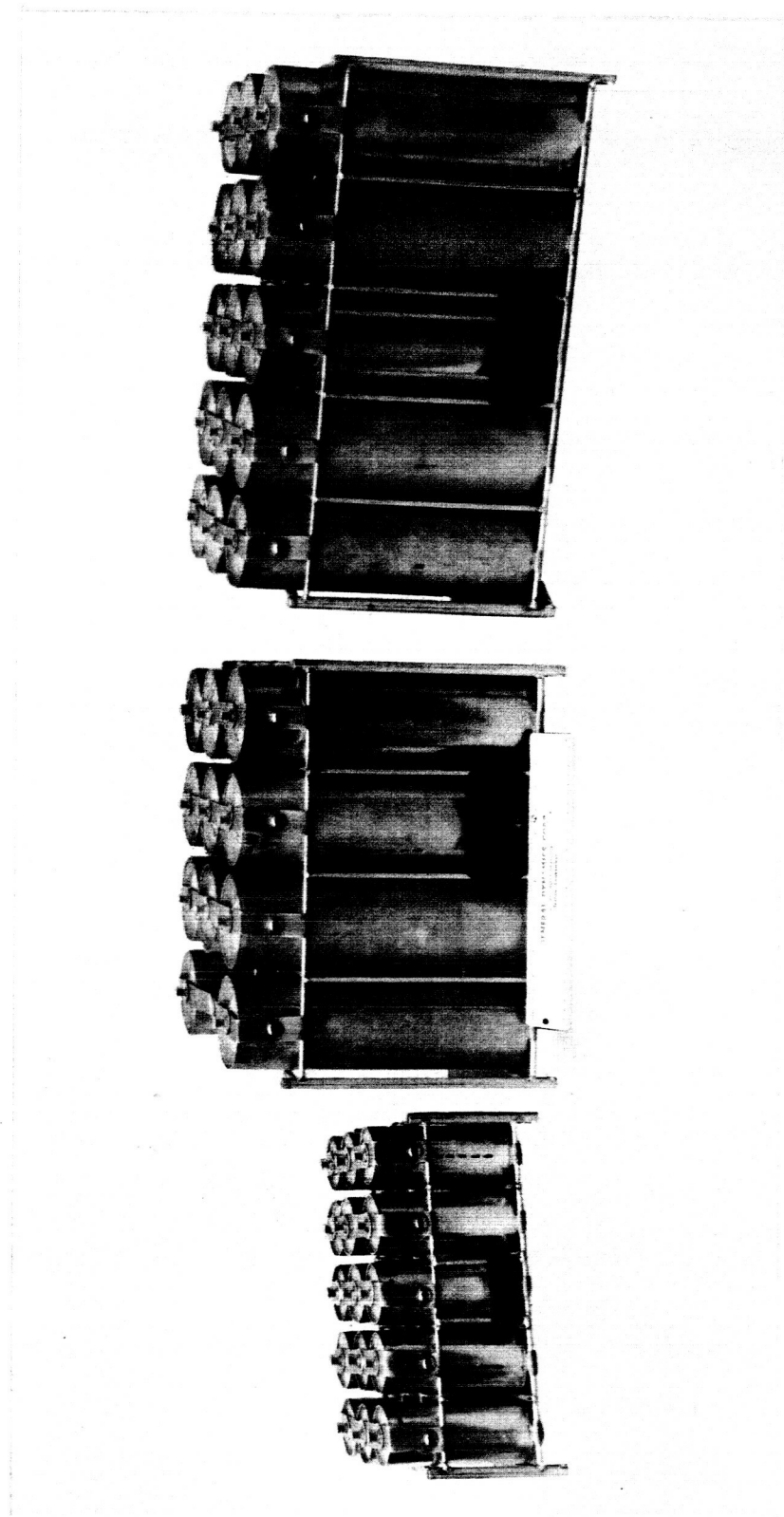


FIGURE 8-9 STORAGE RACKS WITH SPARE FILTERS, RESIN CANISTERS, AND CARBON CANISTERS

Table 8-2. It should be noted that the storage container weights are somewhat high because of the use of brass grommets and snaps. It is also possible that the weights of carbons and resins are high, since the number of spares is based on conservative calculations. Ultimate capacities of the carbons and resins can only be determined by extended tests in space simulators.

Figure 8-10 shows the estimated weights of the three multi-filter systems for different mission lengths. The estimated weights are based on the quantities of waste waters assumed in the design of the subsystems (see Section II). These quantities of water are obviously for a three or four-man crew. It should be noted that all resin weights include some water as it must be maintained in a moist condition.

Figure 8-10

WEIGHT VERSUS MISSION LENGTH FOR THREE
MULTI-FILTER SUBSYSTEMS

BASED ON THE FOLLOWING DAILY
FILTRATION CAPACITIES:

WASH WATER 12 LBS.
FECAL WATER 1 LB.
DECONTAMINATION WATER 7.5 LBS.

200

SUBSYSTEM WEIGHT (LBS)

150

100

50

0

0 1 2 3 4 5 6

12

18

24

LENGTH OF MISSION (MONTHS)

WATER FILTRATION SUBSYSTEM

FECAL WATER SUBSYSTEM

DECONTAMINATION WATER SUBSYSTEM

TABLE 8-2

SUMMARY OF ACTUAL SUBSYSTEM WEIGHTS
(ONE YEAR MISSION)

<u>Wash Water Subsystem</u>	<u>Weight (lb)</u>
Activated carbon	28.5
Carbon containers (13)	7.41
Ion exchange resin	49.2 *
Resin containers (12)	6.84
Filter elements (12)	2.45
Filter housings (12)	2.28
Fasteners and mounting	3.42
TOTAL	100.10
 <u>Fecal Water Subsystem</u>	
Activated carbon	13.2
Carbon containers (5)	2.85
Ion exchange resin	7.46
Resin containers (2)	1.14
Filter elements (2)	0.41
Filter housings (2)	0.38
Fasteners and mounting	3.42
TOTAL	28.86
 <u>Dehumidification Water Subsystem</u>	
Activated carbon	5.28
Carbon containers (2)	1.14
Filter elements (4)	0.84
Filter housings (4)	0.76
Fasteners and mounting	1.32
TOTAL	9.34
 <u>Storage Containers</u>	
Carbon canister storage container	2.80
Resin canister storage container	2.34
Filter storage container	1.77
TOTAL	6.91
 GRAND TOTAL OF THREE SUBSYSTEMS AND STORAGE CONTAINERS	 145.2
*The ion exchange resin weight for wash water is somewhat high (by about 2.9 lb) because of water left in the container due to rinsing.	

IX

TESTING OF SUBSYSTEMS

This section describes test results with the subsystems as finally designed. Because of the limited quantities of waste water available and because of limited time, extended testing could not be undertaken. However, the test results obtained do show that the treated water from each subsystem meets the required specifications. Frequency of canister replacement was not determined experimentally, but was calculated from theoretical considerations and from prior laboratory results. The numbers of spare canisters and filters provided for each subsystem is given in Table 6-1. Canister and filter life for the wash water subsystem is expected to be 1 month. Life expectancy for canisters in the other two subsystems varies from 3 to 6 months. Since replacement frequency is highly dependent on composition of the waste waters, canister life can best be determined in extended tests with manned space simulators.

9.1 WASH WATER SUBSYSTEM

Steele, et al (1962) carried out preliminary loading tests using carbon and resin to determine the most effective multi-filter system for wash water reclamation. They also tested benzalkonium chloride (BAC) as a washing (and antiseptic) agent.

For evaluating the wash water subsystem, a concentration of 0.05% BAC was chosen as the washing agent. About 12 lb of used wash water from three volunteers were treated in the wash water subsystem and the clean effluent collected. Four pounds of this effluent were used for all subsequent testing. This clean effluent was soiled by daily bathing, purified in the subsystem, and re-used through five complete cycles. Small quantities of water were removed for samples and this loss was corrected by adding used wash water before recycling. The flow rate of the wash water was maintained at approximately 10 ml/min. (1.3 lb/hr) resulting in a pressure drop of 0.5 to 2 psig. An occasional increase

in pressure drop was observed and found to be due to air trapped in the carbon canisters. Occasional depressurization of the feed tank was necessary to prevent continued increase in pressure drop.

9.1.1 Analytical Test Methods

A "Photovolt" pH meter was used for determining the hydrogen ion concentration.

A "Solu Bridge" with a dip-type conductivity cell manufactured by Industrial Instruments, Inc. was used for the conductivity measurements.

NH_4^+ , Cl^- , SO_4^{--} , and urea were determined qualitatively as follows:

Cl^- - Silver nitrate test solution

SO_4^{--} - Barium chloride test solution

NH_4^+ - Nessler reagent

Urea - hydrolysis with urease, then addition of Nessler reagent

Benzalkonium chloride (BAC) - "pHydrion" paper QT-10 for testing quaternary compounds colorimetrically by comparison with color chart.

Chemical Oxygen Demand (COD) - Rapid method of Porges, et al (1960) was used.

Total solids - gravimetric method by evaporating water at 105°C until constant weight.

9.1.2 Difficulties Encountered

Preliminary tests were made in a laboratory model of the wash water subsystem to confirm effectiveness of the scheme of beds of cation and anion exchange resins as originally designed. It was found that the effluent water had pH's of 3.1 and 3.4 and it was therefore necessary to remove part of the Duolite C-3 (included for adsorption of urea) and replace it with Rohm and Haas XE-168 anion exchange resin. Testing of the effluent water from this improved setup gave the following results:

pH - 7.6

Specific conductivity - 26 micromhos/cm

Odor - slightly resinous (from ion exchange resin)

Cl⁻ - negative

Urea - negative

This scheme resulted in a satisfactory pH, and resin canisters were reloaded accordingly (layer of IR-120, then XE-168, C-3, and XE-168 at end).

A carbon canister (CAL carbon) was flushed with de-ionized water; the conductivity of the effluent was 52 micromhos/cm and the pH was 10.0. After steeping overnight, the conductivity of the effluent was 95. It was not thought necessary to wash this carbon as the effluent was equal to Groton tap water in conductivity, and in actual practice the resin canister downstream would remove the small amount of salts given up by the carbon. However, in future practice pre-washing with de-ionized water and drying of the carbon is recommended to remove all soluble matter.

In initial testing of the wash water system, several problems occurred. Effluent was found to give a positive test for BAC and NH₄⁺. The initial effluent was colored slightly yellow. There was also pronounced taste and odor in the effluent water. These difficulties were traced to the resin canister and more closely to the XE-168 resin and Dacron felt at the downstream end, and to the particulate filter. XE-168 contains tertiary amine functional groups and gave a positive test for BAC and NH₄⁺ due to impurities in the resin which disappeared on washing. It is possible that even though the canisters were immersed in water during the final weld, a limited amount of overheating may have occurred in the vicinity of the Dacron felt or resin. The breakdown of the felt and/or resin would contribute color. Any damage that might have occurred to the contents due to heat or welding was obviously limited, since only a small amount of effluent was discolored and the canisters subsequently purified used wash water satisfactorily. The Pall particulate filter released considerable odor and taste to water being passed through, and

showed slightly positive when subjected to a test for NH_4^+ . The filters had to be washed free of the odor (due to a plasticizer used in the end-seal) with hot water (150°F to 170°F) and vacuum dried at 70°C . Pall Corporation stated that the plasticizer contamination was due to a manufacturing difficulty and it would not occur in future shipments.

When the two carbon canisters in the wash water recovery system were dismantled after testing and the water was blown out, a slight odor of H_2S was evident. Subsequent testing of this water from the carbon canisters with lead acetate paper did not give a positive test for H_2S and the characteristic odor of H_2S disappeared immediately. It is believed that the odor threshold for H_2S is more sensitive than the lead acetate paper qualitative test. The H_2S is probably evolved from bacteria on the carbon acting on the wash water after the BAC (anti-septic) has been removed. This point requires further investigation.

9.1.3 Results and Discussion

The results of testing the wash water recovery subsystem are shown in Table 9-1. The questionable positive test for NH_4^+ has been discussed above and the taste and odor contamination from the filter have also been explained.

A recovery efficiency of 99.0% was calculated for the wash water system. This efficiency was calculated on the basis of the amount of water remaining in the activated carbon, ion exchange resin, and filters after these canisters were drained of water with an aspirator. Excess water can also be drained out by blowing air through the canisters. Losses due to evaporation were not taken into consideration since this water would be recovered by the dehumidification system in a space cabin.

In a review of the chemical composition of sweat, Robinson and Robinson (1954) reported that sulfates were present (4 to 17 mg/100 ml). It is interesting to note that no sulfates were found in the wash water at Electric Boat. This indicates that sulfates were absent from the perspiration of our three subjects.

TABLE 9-1
TESTING OF WASH WATER SUBSYSTEM

Sample	Amounts (lb)	Conductivity (Micromhos/cm)	pH	NH ₄ ⁺	Cl ⁻	SO ₄ ⁻	BAC ¹ (ppm)	Urea	Organoleptic Tests				COD ⁴ (ppm)	Total Solids (ppm)
									Appearance	Odor	Color	Taste		
Original	--	525	4.8	sl. pos.	pos.	neg.	400 ⁺	pos.	turbid & sediment	typical	grayish	--	1200	2350
1st effluent	11	23	7.6	sl. pos. ⁵	neg.	neg.	neg.	neg.	clear	none ²	none	none ²	--	--
1st effluent after use ⁶	4	440	4.6	sl. pos.	pos.	neg.	400 ⁺	pos.	turbid & sediment	typical	grayish	--	--	--
2nd effluent ⁶	4	21	7.5	sl. pos. ⁵	neg.	neg.	neg.	neg.	clear	none ²	none	none ²	--	--
2nd effluent after use ⁶	4	500	4.6	pos.	pos.	neg.	400 ⁺	pos.	turbid & sediment	typical	grayish	--	--	--
3rd effluent ⁶	4	below 20	7.4	sl. pos. ⁵	neg.	neg.	neg.	neg.	clear	none ²	none	none ²	--	--
3rd effluent after use ⁶	4	450	4.6	pos.	pos.	neg.	400 ⁺	pos.	turbid & sediment	slight perfume ³	grayish	--	--	--
4th effluent ⁶	4	below 20	7.3	sl. pos. ⁵	neg.	neg.	neg.	neg.	clear	none	none	none ²	--	--
4th effluent after use ⁶	4	485	4.2	sl. pos.	pos.	neg.	400 ⁺	pos.	turbid & sediment	typical	grayish	--	--	--
5th effluent ⁶	4	below 20	7.2	sl. pos. ⁵	neg.	neg.	neg.	neg.	clear	none	none	none ²	50	26

- 1) Benzalkonium Chloride.
- 2) Actually a slight amount contributed by filter.
- 3) Due to soap previously used by subject.
- 4) Chemical Oxygen Demand is an estimate of the organic material in the sample -- Groton tap water has a COD of 170 ppm.
- 5) This questionable slight positive test has been traced to the XE-168 resin through which the water passes prior to the final filter and to the filter element itself.
- 6) The same 4 lb of effluent was recycled through the system; losses due to sampling, etc. were made up by adding original dirty wash water sample to effluent before recycling.

9.1.4 Conclusions and Recommendations

The tests on the wash water subsystem indicate that not only did the unit yield water suitable for use as clean wash water, but also the effluent water after five cycles apparently met the U. S. Public Health Service drinking water standards (1962).

For future work it is recommended that the carbon canisters be thoroughly flushed with de-ionized water (to remove any salts) and subsequently be sterilized and dried in a hot air oven at 130°C. The resin canisters should also be flushed with de-ionized water to remove impurities which caused false tests.

9.2 DEHUMIDIFICATION WATER SUBSYSTEM

Dehumidification water for testing the system was procured from the space cabin simulator at Wright-Patterson Air Force Base and from the nuclear submarine SSB(N)602. The simulator water had an "organic" odor which was not unpleasant. The submarine water had a strong, unpleasant odor due to the smoking and cooking, etc. and would serve as an example of heavily contaminated dehumidification water. The waste waters were passed through the subsystem at a flow rate of 10 ml/min. giving a pressure drop of from 0.5 to 0.9 psig.

9.2.1 Analytical Test Methods

Methods used are given under "Wash Water Subsystem" paragraph 9.1.1. Total bacterial counts and coliform counts were carried out using the Millipore Filter Technique given in APHA publication "Standard Methods for the Examination of Water and Waste Water" (1960). Ammonia test solution was used for testing for the presence of aluminum.

9.2.2 Difficulties Encountered

In preliminary tests of this system, the first 250 ml of effluent had a conductivity of 45,000 micromhos/cm due to the impurities in the carbon. To eliminate the impurities, the carbon canisters were flushed with de-ionized water until the conductivity reading was below 20 micromhos/cm. The carbon canister was then filled with de-ionized water and allowed to equilibrate for 2 hours or overnight. If the conductivity

reading rose, the washing and equilibrating was continued until the reading was below scale (20 micromhos/cm). The canisters were then dried in a hot air oven at 130°C. Three periods of washing and three periods of equilibration were necessary to thoroughly flush carbon canisters free of soluble impurities. In future work the carbon used should be thoroughly washed, either by the manufacturer or before loading into the canisters.

9.2.3 Results and Discussion

The results of testing recovered water from the space simulator and submarine dehumidification system are shown in Table 9-2.

Recovered simulator water was free of ammonium ions, whereas recovered submarine water was not. Ion exchangers added to the system would improve the quality of the water recovered from the heavily contaminated submarine dehumidification system and also remove the NH_4^+ . The submarine water, after treatment, had about five times as much organic matter as the treated simulator water. It would be interesting to check submarine dehumidification water from a crew of non-smokers as it is believed that the heavy load of impurities in the dehumidification water is largely due to smoking by the crew.

The COD of recovered submarine water seems high. (Groton tap water has 170 ppm; special laboratory sewage effluent* has about 1000.) It is surmised that this high value is due to small volatile organic molecules not adsorbed by the carbon. The total solids values of both original and recovered waters were low and are indicative of non-volatile constituents. The total solids values were essentially unchanged by the multi-filter treatment. The conductivity value of the treated submarine water (200 micromhos/cm) was higher than treated simulator water (65) and Groton tap water (95), but additional treatment with ion exchange resin would remedy this.

*A special sewage effluent from a highly concentrated human waste treated in a laboratory activated sludge digester had a COD value of about 1000.

TABLE 9-2
TESTING OF DEHUMIDIFICATION WATER SUBSYSTEM

Waste Water	Sample	Amount (ml)	Conductivity (Micromhos/cm)	pH	NH ₄ ⁺	Cl ⁻	SO ₄ ²⁻	Al+++	Organoleptic Tests			COD (ppm)	Total Solids (ppm)	Bacteriology	
									Appearance	Odor	Color			Total Count	Coliform
Simulator ¹	original	--	150	7.1	pos.	neg.	neg.	neg.	slightly turbid some sediment	slight not unpleasant	none	450	60	too numerous to count	3/100ml
Simulator	1st effluent	250	67	7.4	neg.	neg.	neg.	neg.	clear	none	none	--	--	none	0/100ml
Simulator	2nd effluent	250	63	7.3	neg.	--	--	--	clear	none	none	--	--	--	--
Simulator	3rd effluent	250	65	7.2	neg.	--	--	--	clear	none	none	--	--	--	--
Simulator	4th effluent	230	66	7.2	neg.	neg.	neg.	neg.	clear	none	none	85	70	--	--
Submarine ²	original	--	450	7.7	pos.	neg.	neg.	--	Slightly turbid much sediment	strong unpleasant stale tobacco smoke	light amber	477	85	--	--
Submarine	1st effluent	250	135	7.4	pos.	neg.	neg.	--	clear	none	none	--	--	--	--
Submarine	2nd effluent	250	210	7.5	pos.	neg.	neg.	--	clear	none	none	--	--	--	--
Submarine	3rd effluent	250	260	7.4	pos.	neg.	neg.	--	clear	none	none	416	60	--	--

1) Dehumidification water from Air Force Simulator received 4/12/63 from Wright Patterson Air Force Base.

2) Dehumidification water from submarine SSB(N)602 collected March 1963.

A recovery efficiency of 99.5% was calculated for the dehumidification system. Calculations were made on the basis of assumptions described in paragraph 9.1.3.

9.2.4 Conclusions and Recommendations

The space cabin simulator water which would more closely resemble actual space conditions was most successfully recovered and no modifications are necessary in this system based on the tests conducted.

The recovered dehumidification water from both the space simulator and submarine were palatable and the multi-filter system operated successfully. The recovered simulator and submarine waters apparently meet the standards for potable water.

Simulator recovered water is of higher quality than submarine recovered water. Further study of the recovered dehumidification water from the submarine would be interesting. Gas chromatography might assist in identifying contaminants and long-term feeding studies with animals would check for possible toxicity due to residual contaminants resulting from smoking by the crew. The positive test for NH_4^+ in submarine recovered water is not considered serious, as treatment with ion exchange resin would remove this contaminant.

9.3 FECAL WATER RECOVERY SUBSYSTEM

The initial design for this fecal water recovery system, based on loading tests and column operation with carbons and resins, is given in Steele, et al (1962). The fecal water used for testing this system was obtained from the MRD Division, General American Transportation Corporation, Niles, Illinois. This water was prepared by distillation of feces and subsequent "light" treatment with activated carbon resulting in a product of slightly unpleasant odor.

KE-1 carbon, as used for the dehumidification water subsystem, and MB-1 ion exchange resin were selected for this unit. Glass columns, 1" I.D., were used instead of the actual subsystem since the amount of fecal water available for testing was too small. The carbon was packed

into a column 23.5" long and the resin packed into a column 12" long. A flow rate of 90 ml/hr was used, resulting in a pressure drop of 0.5 psig across the system. (This flow rate gives the same bed velocity as the designed rate for the subsystem.)

9.3.1 Analytical Test Methods

The methods used for testing fecal water are the same as those used for wash water and dehumidification water.

9.3.2 Difficulties Encountered

The soluble solids were flushed out of the carbon canisters before testing using the method outlined under dehumidification water; however, a suitable method had not been developed at this time for removing impurities from the filter elements so that contaminants as NH_4^+ and odor from the filter (the effluent was not tasted) were present in the fecal effluent. The manufacturer's recommendation for removing impurities from the filter element by air purging was ineffective. As noted previously, it was later found that continuous flushing with hot water ($150^\circ - 170^\circ\text{F}$) for about 3 days was necessary to remove traces of odor and flavor imparted to the water.

9.3.3 Results and Discussion

The results of the test program for the fecal water subsystem are given in Table 9-3. The reason for odor in the effluent and the questionable positive test for NH_4^+ are explained above and were due to contamination from the filter. A recovery efficiency of 96.0% was calculated for this system.

The quality of the water received from General American Transportation Corp. is superior to the quality of water used during the design study phase of this program, and the amounts of carbon and resin supplied in this subsystem will probably be much more than required for a 1-year mission.

It was expected that coliform bacteria (as well as other micro-organisms) would be absent or low in the feed water since they would be destroyed

TABLE 9-3
TESTING OF FECAL WATER SYSESTEM

Sample	Volume (ml)	Conductivity (Micromhos/cm)	pH	NH ₄ ⁺	Cl ⁻	SO ₄ ²⁻	Organoleptic Tests			COD ⁴ (ppm)	Coliform Bacteria	Total Solids (ppm)
							Appearance	Odor	Color			
Original Fecal Water ¹	--	500	9.0	pos.	neg.	neg.	clear	slightly unpleasant	none	185	neg.	45
1st effluent	500	35	7.3	pos. ²	neg.	neg.	clear	none ³	none	--	--	--
2nd effluent	500	35	7.4	pos. ²	neg.	neg.	clear	none ³	none	--	--	--
3rd effluent	500	below 20	6.4	pos. ²	neg.	neg.	clear	none ³	none	70	--	85 ⁵

- 1) Fecal water received 4/15/63 from MRD Division, General American Transportation Corporation, Niles, Illinois.
- 2) Positive test for NH₄⁺ was found to be caused by NH₄⁺ being given off by filter element as effluent was neg. before entering filter.
- 3) Slight odor was actually present due to pick up from filter; effluent was odorless before entering filter.
- 4) Chemical Oxygen Demand is an estimate of the organic material in the sample - Groton tap water has COD of 170 ppm.
- 5) Believed caused by pick up of solids from filter element.

during the distillation procedure in the production of the fecal water from feces. This was found to be the case.

9.3.4 Conclusions and Recommendations

The fecal water subsystem furnished water of high quality. This water would not only be suitable for washing, but, based on the results obtained, would also probably be suitable for drinking (water was not actually tasted).

Proper prewashing and drying of both the carbon and the filter (or improved manufacturing methods) as mentioned previously, is necessary to remove contaminants from these materials.

OPERATION OF SUBSYSTEMS

10.1 GENERAL

The multi-filter subsystems are relatively simple to operate. The fecal water and wash water subsystems are arranged with two carbon canisters in series, followed by an ion exchange resin canister and a particulate filter. The dehumidification water subsystem consists of a carbon canister and a bacterial filter in series.

Zero "g" operation would differ from 1 "g" operation only in the design of the feed and receiving tanks. For zero "g" operation, tanks could be made with diaphragms backed up with springs or compressed air. Plexiglass tanks were furnished for laboratory or simulator test purposes and are convenient in that the contents (volume and appearance) of both the feed and treated water can be seen at all times. Flow rates can be estimated by measuring the level change per unit of time.

10.2 OPERATING PROCEDURE

The following sequence is recommended for operation of all subsystems:

1. Make all connections between subsystems and tanks as indicated in Figure 10-1 and Figure 10-2.
2. Turn both valves to OFF position and fill feed tank with waste water. (The system may also be prefilled with tap water to prevent initial by-passing).
3. Turn on compressed air (controlled at 1 psig) to pressurize feed tank.
4. Turn both valves to PROCESS position and allow water to flow through the subsystem until it appears in the treated water (or receiving) tank.

- (1) Air purge line from compressed air supply
- (2) Sample line
- (3) Compressed air supply
- (4) Reclaimed water to receiving tank
- (5) Replacement filter
- (6) Feed tank
- (7) Receiving tank
- (8) Carbon canisters
- (9) Resin canister
- (10) Filter
- (11) Replacement canister
- (12) In valve
- (13) Out valve

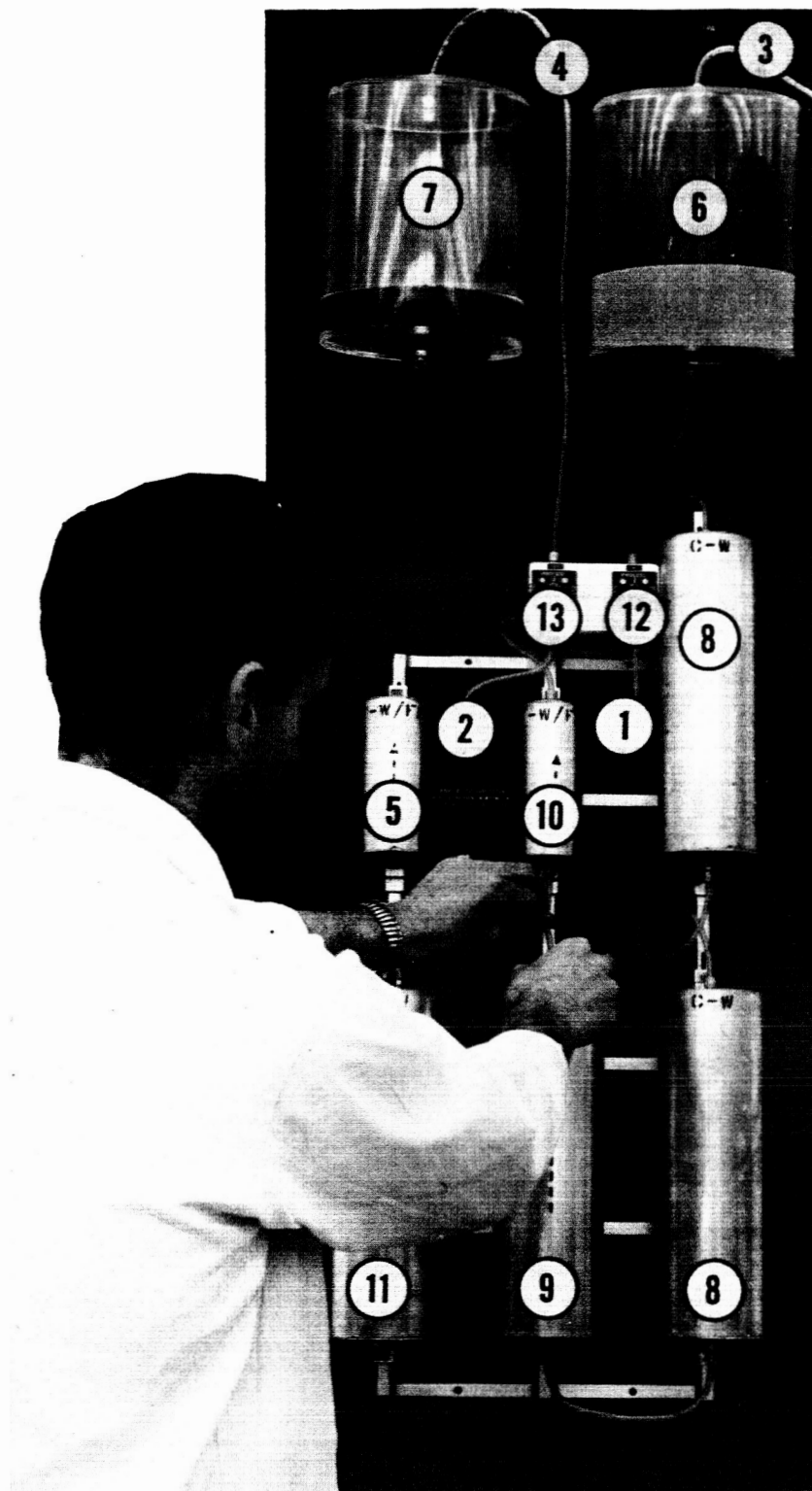


FIGURE 10-1 CHANGING CANISTERS ON THE WASH WATER SUBSYSTEM

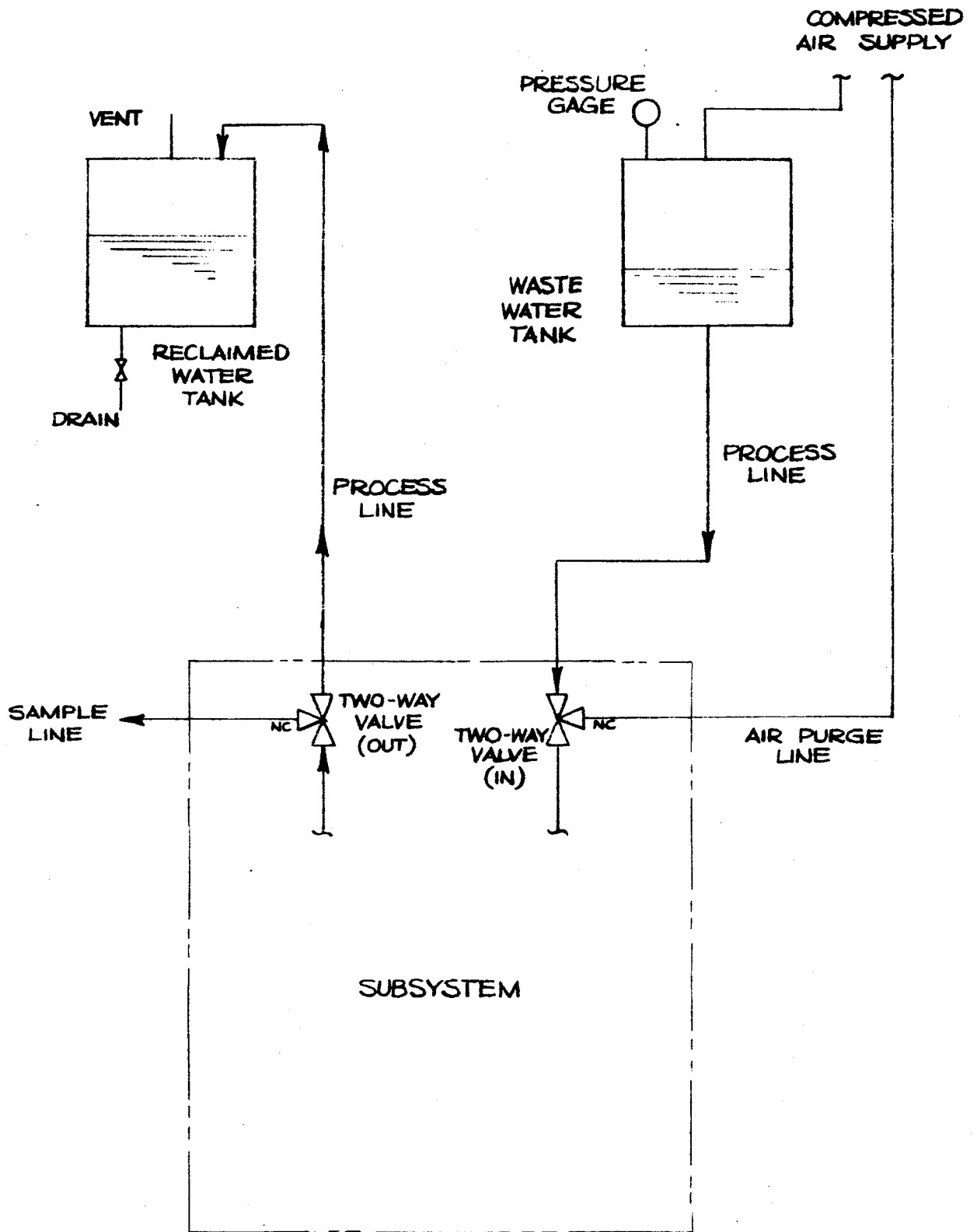


figure 10-2
 FLOW DIAGRAM—WASTE WATER RECOVERY
 BY MULTIFILTRATION

5. Meter water through subsystem at the following approximate rate:

Wash Water Subsystem - 9 ml/min.

Dehumidification Water Subsystem - 6 ml/min.

Fecal Water Subsystem - 2 ml/min.

The flow rate can be controlled by adjusting the feed tank air pressure (between 0 - 2 psig). If it is found difficult to obtain a steady flow rate, then vary the restriction of the OUT valve until a satisfactorily steady flow rate is obtained. (Note: Flow rate for any subsystem is not critical. The system was designed to treat the daily waste water in 10 hours but will work equally well at double or half this rate.) In using air pressure in the feed tank, it may be necessary to occasionally depressurize the system to release air trapped in the canisters. An alternate method of controlling flow is to apply a partial vacuum (0 - 2 psig) to the receiving tank instead of applying air pressure to the feed tank.

6. The OUT valve, SAMPLE position can be used at any time to obtain a "grab" sample of the treated water.

The following procedure is recommended for changing canisters:

1. Turn both valves to OFF position and depressurize the feed tank.
2. The AIR PURGE line should be connected to the compressed air supply (controlled at 0 - 2 psig). Turn IN valve to AIR PURGE position and then turn OUT valve to PROCESS position. Allow water to drain out of the system. (Note: Under weightless conditions, the system could be emptied by using water directly for washing; i.e., with OUT valve in SAMPLE position treated water can be run directly into sponge or wash-cloth.)
3. When subsystem is empty, turn both valves to OFF position, disconnect tubing and replace canisters (see Figure 10-1). Carbon canisters should be replaced counter currently, that

is, upstream canister should be removed, downstream canister moved to the upstream position, and a new canister should be placed in the downstream position. Used canisters should be inverted in the storage rack to indicate that they are exhausted. (See Table 8-1 for canister notations.)

Provision has been made in each subsystem for the temporary storage of one large and one small canister. This is designed to facilitate canister changing under zero "g" conditions. The following sequence should be followed when changing a canister:

1. Place new canister in temporary storage position and clamp in place. (Canister lips should engage clamps approximately the same distance at both ends.)
2. Disconnect tubing from canister to be replaced.
3. Transfer caps from new canister to used canister.
4. Remove used canister and place in storage rack in inverted position. Canisters are secured in the storage rack by a nylon strap. The free end of this strap is inserted in the corner space and slid into place between canister and tubular frame, pulled taught, and snap fastened.
5. Move new canister to operating position.
6. Connect tubing.

In emergencies, carbon canisters and resin canisters can be interchanged between subsystems; i.e., resin canisters designated for the wash water subsystem can be used in the fecal water subsystem, carbon canisters designated for use in the dehumidification water subsystem can be used in the wash water subsystem, and so on. Interchanging of this sort is possible since the different ion exchange resins have the ability to remove inorganic salts and all the carbons remove organic compounds. The different carbons and resins selected are, of course, most effective in the subsystems for which they are designated

XI

CONCLUSIONS

1. From a weight and reliability analysis of the five processes studied, it was concluded that the multi-filter system and the electrodialysis-adsorption system were the most desirable. The weights of these two systems were estimated to be lower than for any of the distillation schemes studied. The multi-filter scheme was recommended for all three subsystems on the basis of its high reliability, simplicity, and zero power requirement.
2. The three multi-filter subsystems were tested and found to give recovered water of the required quality. The dehumidification water subsystem produced potable water from air-conditioning condensate obtained from a space simulator. The wash water subsystem and the fecal water subsystem both produced water suitable for use as wash water.
3. The actual weights of the multi-filter subsystems for a 1-year mission are:

Dehumidification Water Subsystem	-	9.3 lb
Wash Water Subsystem	-	100.1 lb
Fecal Water Subsystem	-	28.9 lb
Storage racks for space canisters	-	6.9 lb
- These weights are not minimum and could be reduced by further design and development.
4. The frequency of canister replacement, and hence subsystem weights, are highly dependent on the composition of the waste waters. Canister life can best be determined by test operation in a manned space simulator.

5. Based on the amount of water remaining in the subsystems, the following water recovery efficiencies were calculated:

Dehumidification Water Subsystem	-	99.5%
Wash Water Subsystem	-	99.0%
Fecal Water Subsystem	-	96.0%

6. Rigid specifications and careful quality control are required to prevent contamination of the treated water with the carbon, ion exchange resin, or filter elements used.
7. Four lb of wash water were found to be sufficient for bathing purposes and it is felt that even a lesser amount might be sufficient. Wash water contamination was not found to vary appreciably with frequency of bathing. Therefore, it can be concluded that clothing absorbs a good proportion of the substances excreted through the skin.

XII

RECOMMENDATIONS FOR FURTHER STUDY

1. Laboratory tests should be run with a silver-activated ion exchange resin for possible reduction in resin requirements for the wash water subsystem.
2. Test procedures should be established and a "zero g test kit" developed for measuring the quality of the recovered water from each of the subsystems.
3. Tests should be run with exhausted activated carbon to determine the feasibility of reactivation, using high vacuum with or without heat.
4. The wash water subsystem should be tested on a recycle basis for 1 to 2 months to determine the frequency of canister replacement and the rate and type of impurities that build up.
5. The capacities of the three subsystems should be determined in a manned space simulator by running each to the breakthrough point.
6. Additional corrosion tests should be made over a several month period to establish the necessity of coating the aluminum and select an optimum coating. Polyethylene liners are suggested as a simple means of preventing the possibility of any pitting.

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